WBS 6.6: Muon Phase II Upgrade

Tom Schwarz
University of Michigan

On behalf of USATLAS Muon Community

US ATLAS Phase II Scrubbing Meeting
Nov 24th, 2015

Outline

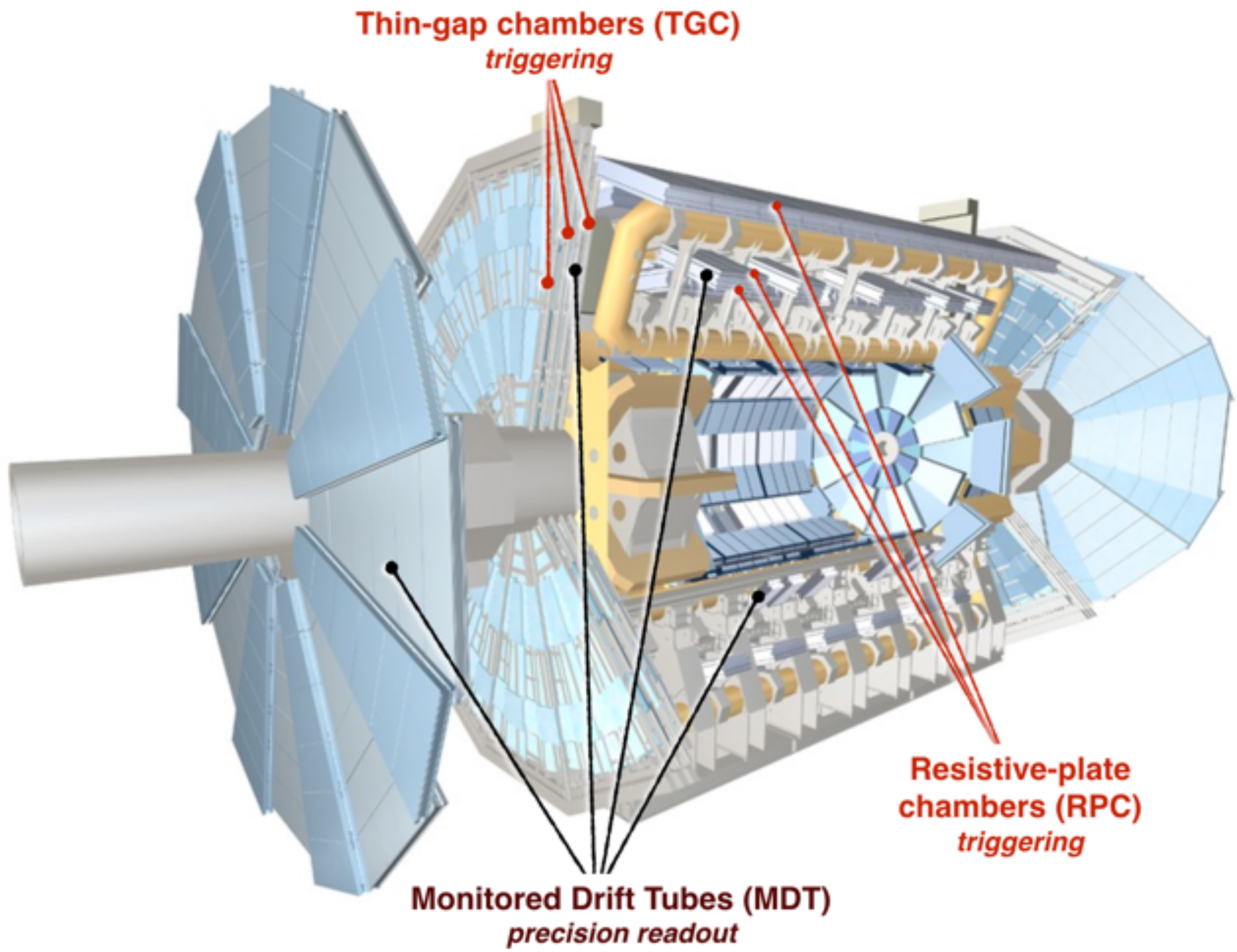
- ATLAS Scope
- USATLAS Scope

  1. Mezzanine
     - PCB (Arizona)
       - *Scope*
       - *Labor Overview*
       - *Travel*
       - *M&S*
       - *Construction*
     - TDC (Michigan)
     - VMM (BNL)
  2. CSM (Michigan)
  3. HEB (Illinois)
  4. sMDT (Michigan)

- Total Costs and Prioritization
- Comparison to ATLAS Core

ATLAS Muon Spectrometer

Phase II upgrades to the muon spectrometer are required to handle increased rates and fakes associated with HL-LHC luminosities and the new ATLAS wide L0/L1 trigger system



ATLAS Muon Spectrometer

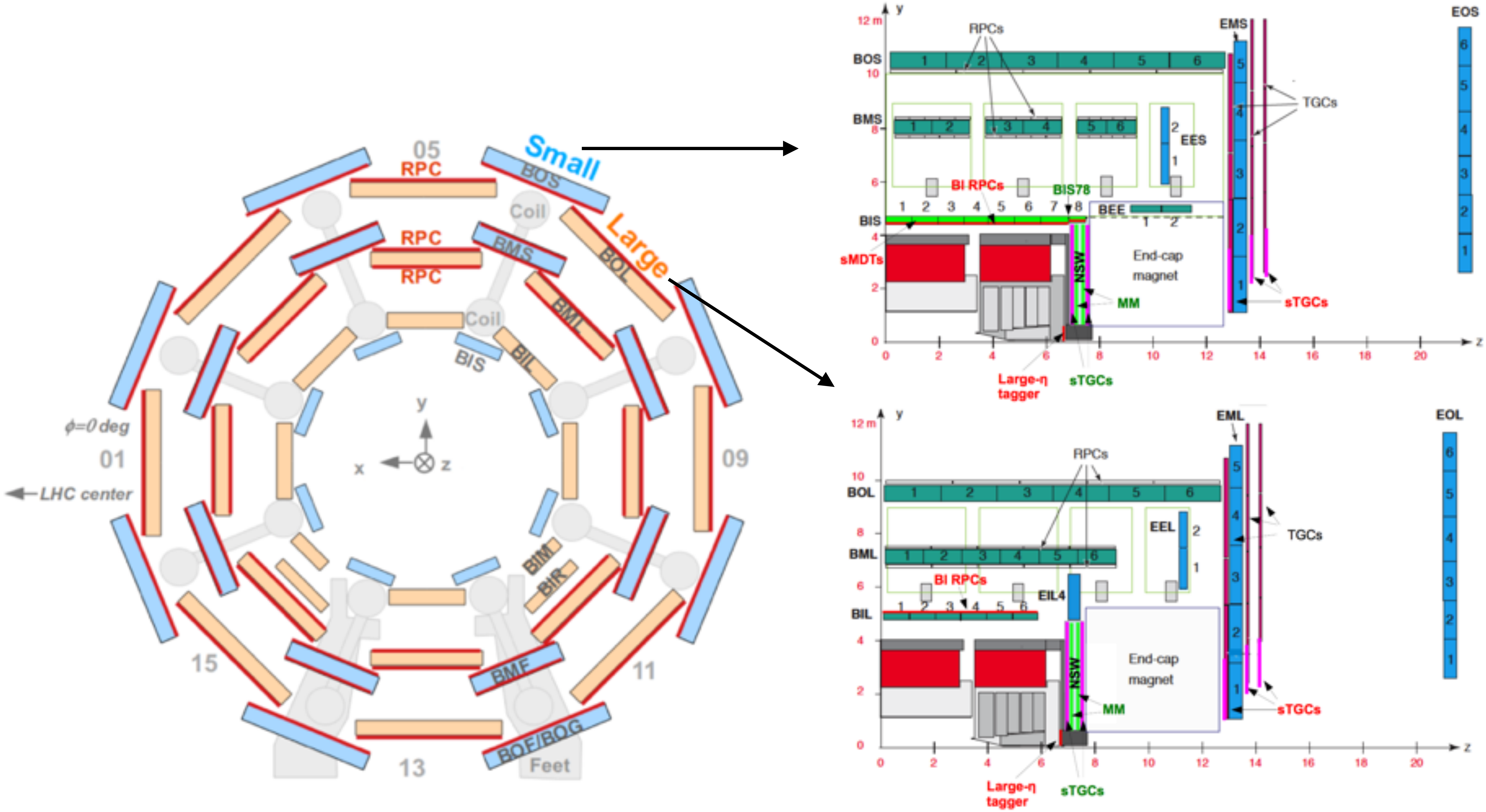
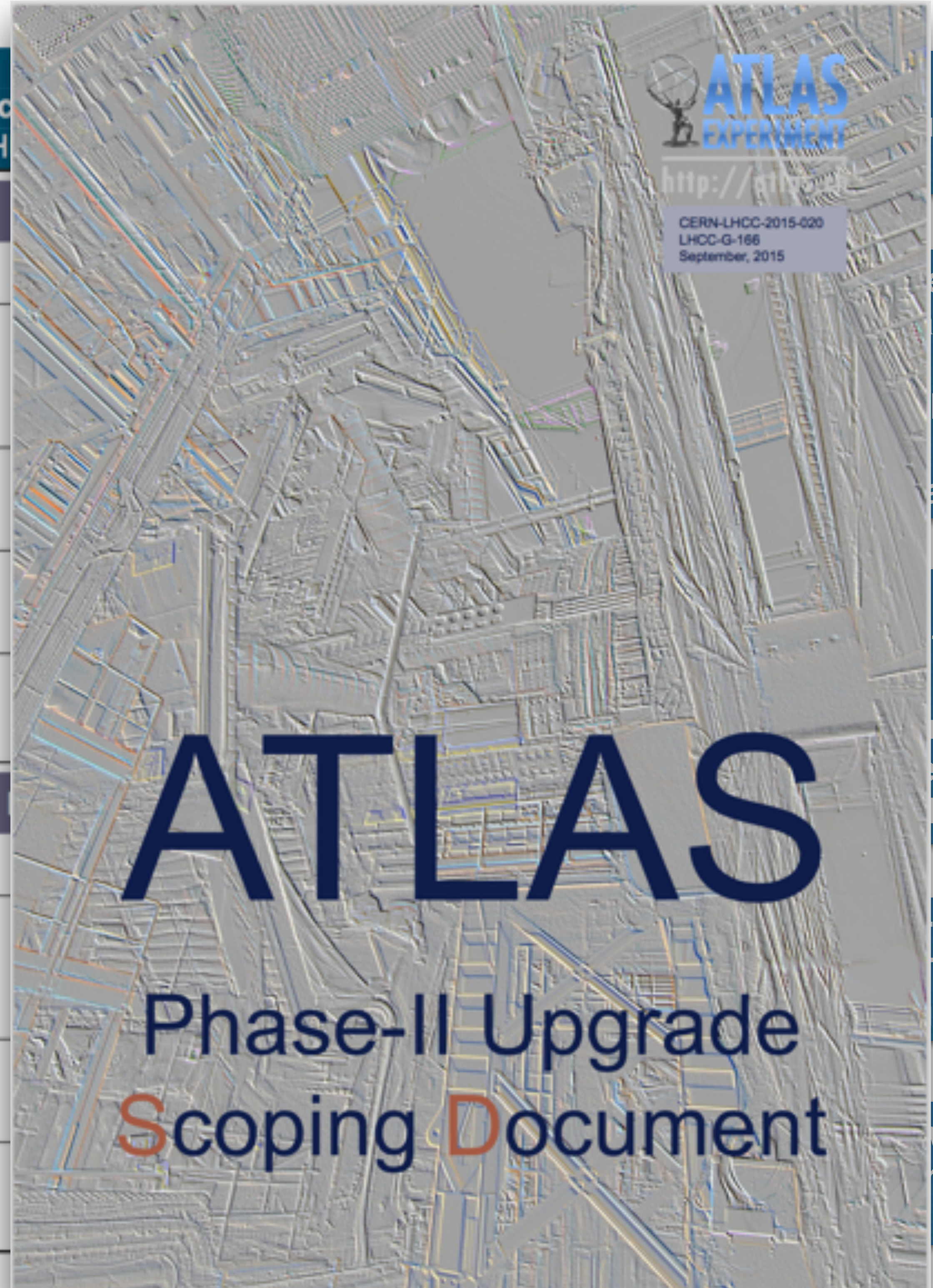


Figure 46. Drawings of the ATLAS Muon Spectrometer with the new chambers proposed for installation in the Phase-II upgrade (red text: BI RPCs, sMDTs, sTGCs, Large-η tagger), those to be installed during LS2 (green text: Micromegas and sTGCs in the new small wheel and RPCs and sMDTs on BIS78), and those that will be kept unchanged from the Run 1 layout (black text). The green (blue) chambers indicated as BMS/BML, BOS/BOL, BEE (EIL, EES/EEL, EMS/EML, EOS/EML) are MDTs. The upper panel shows the R-Z view of one of the azimuthal sectors that contain the barrel toroid coils ("small" sector), the lower panel shows a sector between the barrel toroid coils ("large" sector).

Phase II Upgrade for Muons

Muon Spectrometer	Referenc (275 MCH
Barrel Detectors and Electronics	
RPC Trigger Electronics	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓
RPC Inner layer in the whole layer	✓
Barrel Inner sMDT Detectors in the whole layer	✓
MDT L0 Trigger Electronics (BI +BM+BO)	✓
End-cap and Forward Muon Detectors and	
TGC Trigger Electronics	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓
sTGC Detectors in Big Wheel Inner Ring	✓
Very-forward Muon tagger	✓



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Phase II Upgrade for Muons

Muon Spectrometer	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Barrel Detectors and Electronics			
RPC Trigger Electronics	✓	✓	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓	✓ [BM+BO only]	✓ [BM+BO only]
RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

Barrel (RPC) and end-cap (TGC) triggering electronics must be replaced to cope with hit rates at the HL-LHC.

MDT readout electronics must be replaced to cope with hit rates at the HL-LHC.

To reduce fakes, MDT information will be integrated the into L0/L1 trigger to sharpen p_T selectivity of tracks.

Gas gain on currently installed RPC's must be lowered to meet lifetime limitations (0.3 C/cm^2).

To maintain trigger efficiency, RPC's will be installed at the inner layer. To make room for RPC's at BIS, sMDT's will replace MDT's.

TGC's at inner ring of the Big Wheel will be replaced with sTGC to reduce fakes by improving η spatial resolution.

Add a very-forward muon tagger (between end-cap calorimeter and JD) to allow tagging of inner detector tracks as muons ➔ 2.7< η < 4.0

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Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

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End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
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Very-forward Muon tagger	✓	✗	✗

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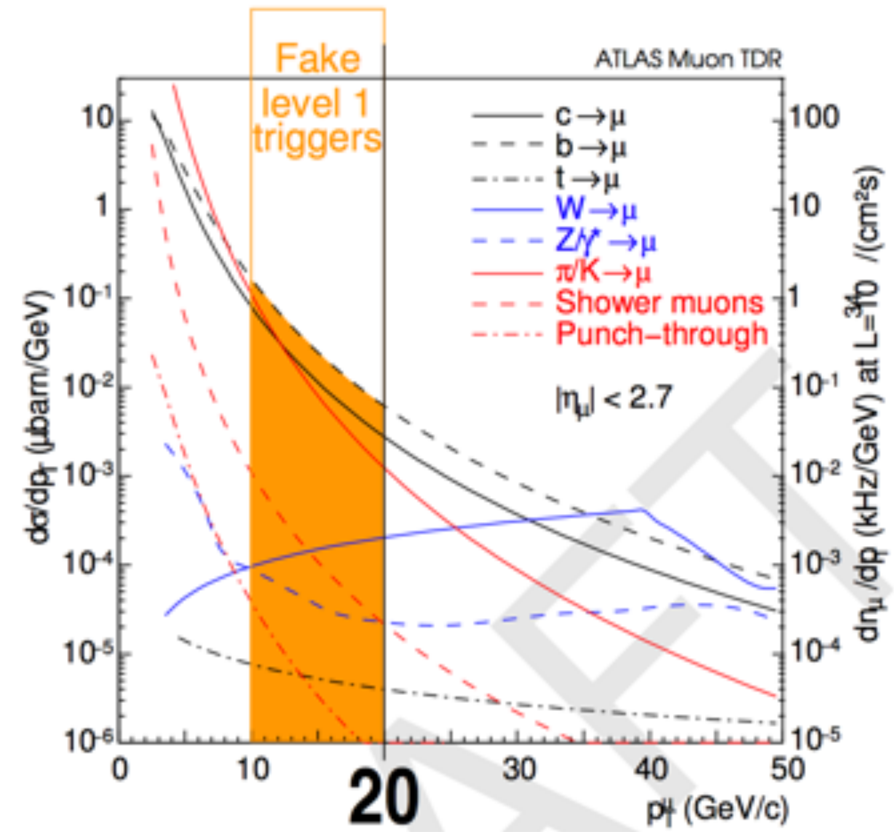

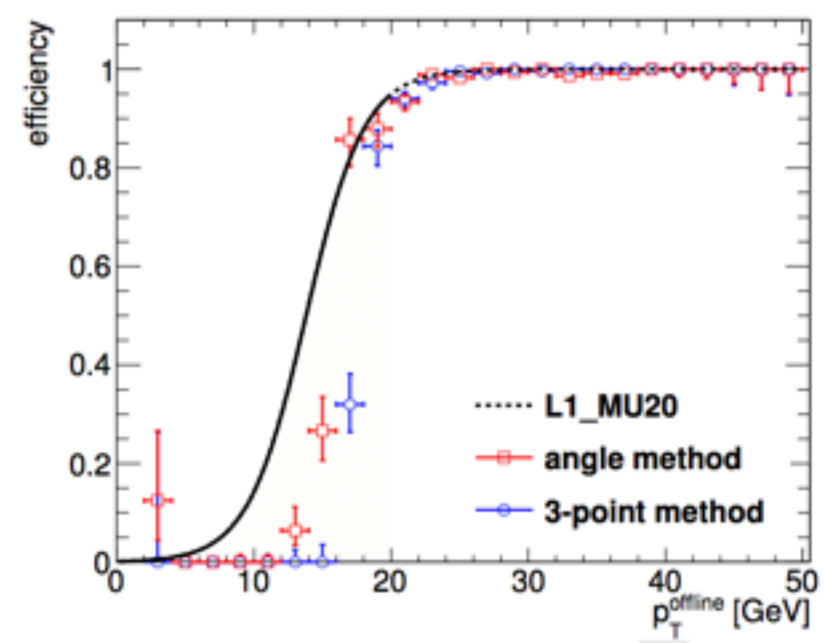

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sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

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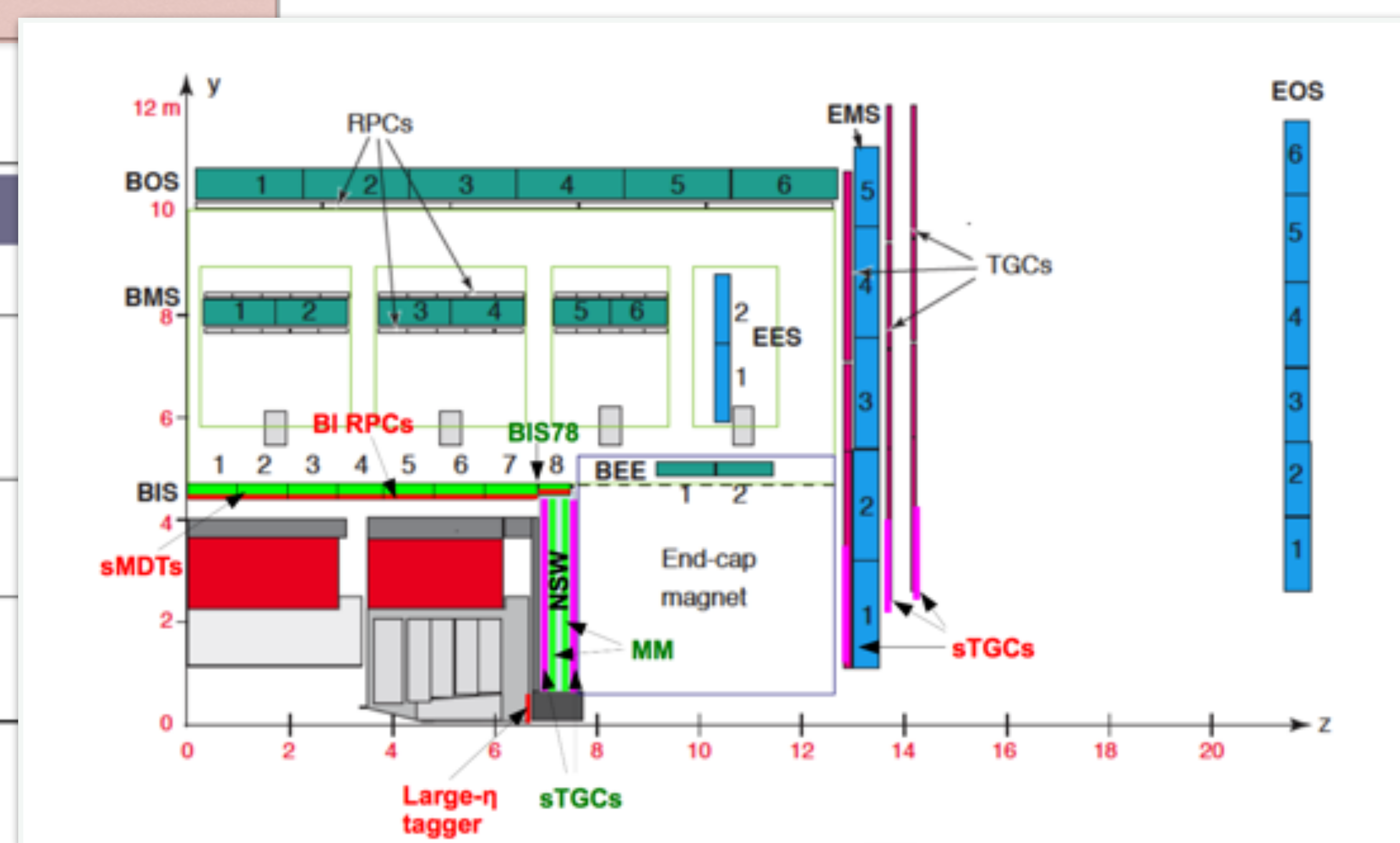
Very-forward Muon tagger	✓	✗	

Trigger	L0 Trigger Efficiency
old RPCs	0.65
+BI RPCs (stations 4-6)	0.82
+BI RPCs (fulll)	0.94



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MDT L0 Trigger Electronics (BI +BM+BO)	✓	[BI	
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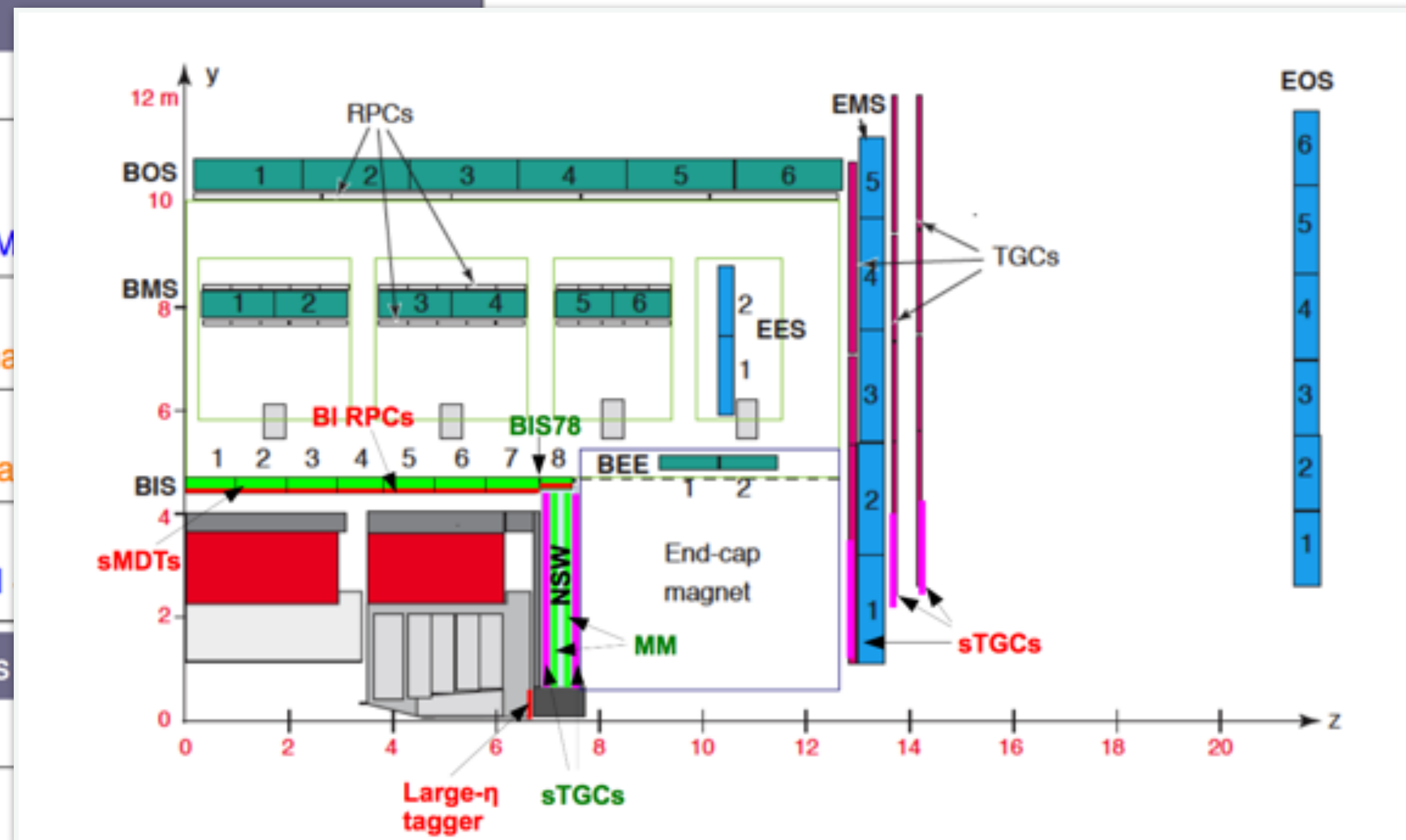

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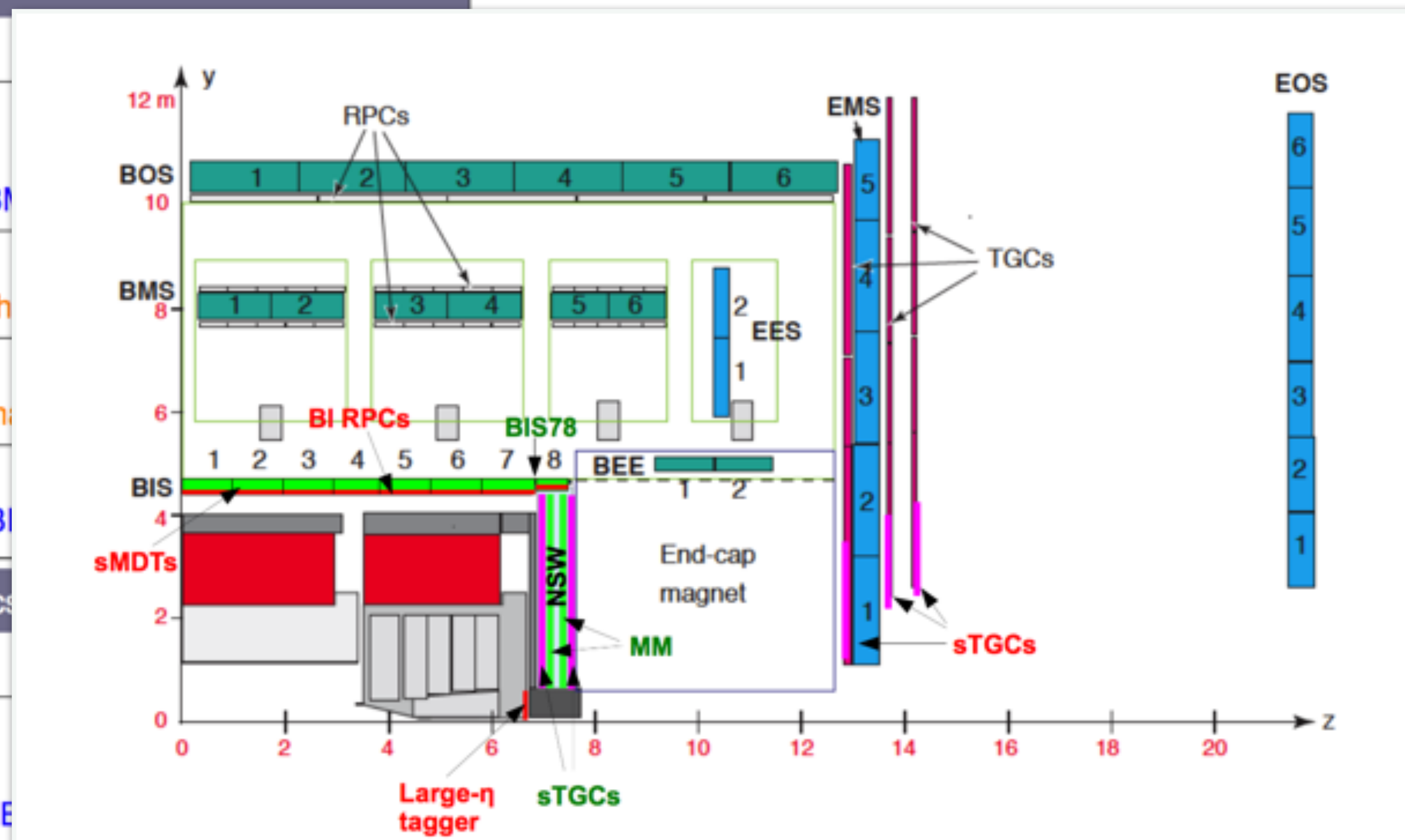
MDT L0 Trigger Electronics (BI +BM+BO)	✓	[BI	
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓		
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	[EE	
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗



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End-cap and Forward Muon Detectors and Electronics			
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MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

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USATLAS Scope for Phase II Muons

Muon Spectrometer	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Barrel Detectors and Electronics			
RPC Trigger Electronics	✓	✓	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓	✓ [BM+BO only]	✓ [BM+BO only]
RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

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η spatial resolution.

USATLAS scope is to lead the design and construction of the trigger and readout electronics for the MDT system

- **Leverages US expertise (MDT, NSW)**
- **High impact contribution**
- **Reasonable costs and low risk**

Add a very-forward muon tagger (between end-cap calorimeter and JD) to allow tagging of inner detector tracks as muons → 2.7< η < 4.0

ATLAS CORE Costs

Muon Spectrometer	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Barrel Detectors and Electronics			
RPC Trigger Electronics	✓	✓	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓	✓ [BM+BO only]	✓ [BM+BO only]
RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650
5.2	**RPC**	**7,989**
5.2.1	Detectors	3,034
5.2.2	Installation mock-up	50
5.2.3	Installation tooling	100
5.2.4	On-detector electronics (DCT)	4,805
5.3	**TGC**	**4,436**
5.3.1	On-detector electronics (PS)	2,136
5.3.2	sTGC on BW inner ring	2,300
5.4	**High η-tagger**	**3,500**
5.4.1	Detector	1,100
5.4.2	FE electronics	1,500
5.4.3	Services+infrastructure	900
5.5	**Power System**	**10,467**
5.5.1	MDT	2,770
5.5.2	RPC	4,227
5.5.3	TGC	3,470

US ATLAS Scope: the MDT System

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RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

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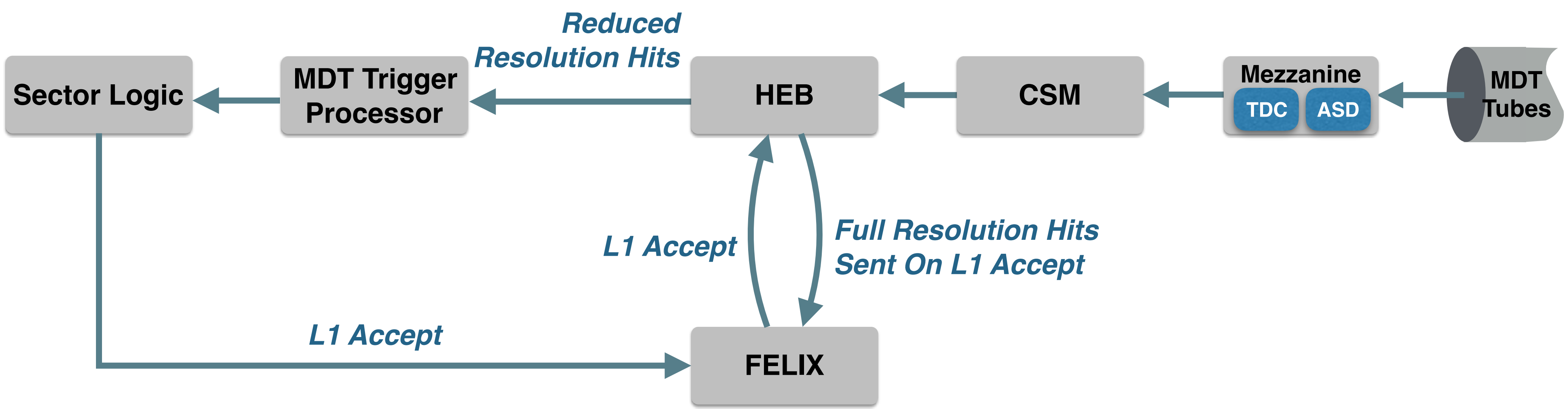
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650
5.2	**RPC**	**7,989**
5.2.1	Detectors	3,034
5.2.2	Installation mock-up	50
5.2.3	Installation tooling	100
5.2.4	On-detector electronics (DCT)	4,805
5.3	**TGC**	**4,436**
5.3.1	On-detector electronics (PS)	2,136
5.3.2	sTGC on BW inner ring	2,300
5.4	**High η-tagger**	**3,500**
5.4.1	Detector	1,100
5.4.2	FE electronics	1,500
5.4.3	Services+infrastructure	900
5.5	**Power System**	**10,467**
5.5.1	MDT	2,770
5.5.2	RPC	4,227
5.5.3	TGC	3,470

MDT Trigger and Readout Electronics



- Raw drift signals for up to 24 tubes are amplified, shaped and digitized by ASD chips, then routed to the TDC which stores arrival times of the leading and trailing edges of the signal.
- At the CSM, data are formatted, stored, and sent via optical link to the Hit Extraction Board (HEB).
- The HEB sends reduced resolution hits to the trigger processor which performs segment finding and track fitting.
- On Level 1 accept by sector logic, the HEB sends full resolution hits to FELIX for readout.

USATLAS Deliverables and WBS

L3 Definitions

1. Arizona
2. Boston University
3. Michigan
4. Illinois
5. BNL

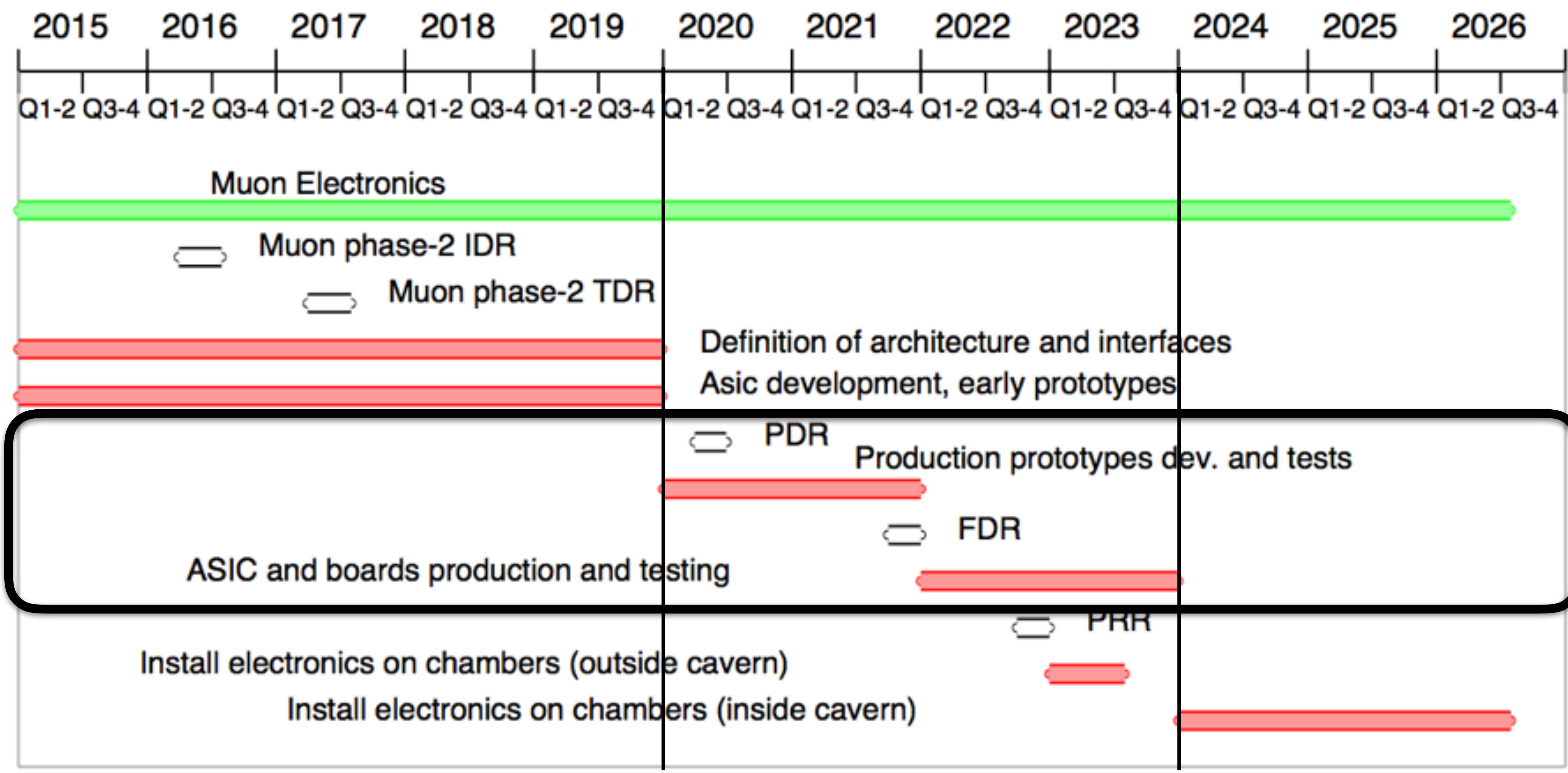
L4 Definitions

1. PCB for Mezzanine
2. TDC
3. CSM
4. HEB
5. sMDT

6.6 SUBSYTEM MUON: WBS

Fund	WBS	Tag	Description
	6.6		**Muon**
	6.6.1		**Muon_Arizona**
	6.6.1.1		**PCB for Mezzanine**
			Design
			Prototype
			Production
	6.6.2		**Muon_BostonU**
	6.6.2.1		**PCB for Mezzanine**
			Design
			Prototype
			Production
	6.6.3		**Muon_Michigan**
	6.6.3.2		**TDC**
			Design
			Prototype
			Production
	6.6.3.3		**CSM**
			Design
			Prototype
			Production
	6.6.3.5		**sMDT**
			Tooling Construction
			Tube Construction
			Chamber Construction
	6.6.4		**Muon_Illinois**
	6.6.4.4		**HEB**
			Design
			Prototype
			Production
	6.6.5		**Muon_BNL**
	6.6.5.2		**TDC**
			Design
			Prototype
			Production

ATLAS Muon Schedule

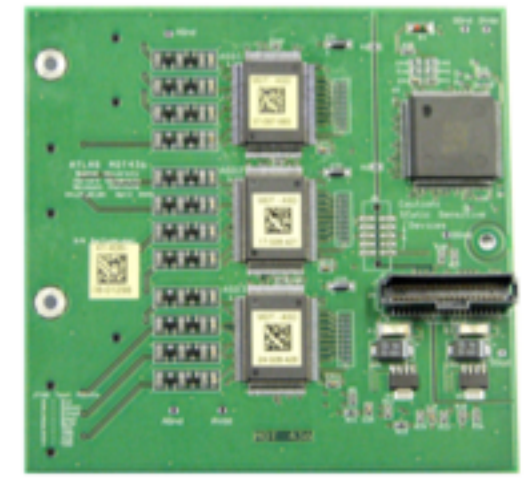


Some General Costing Notes

- No contingency
- Travel assumes 3.5k per international trip, 2k per domestic, including overhead
- All Labor includes overhead, benefits
- No overhead on production or prototypes > $100k
- No spares, but includes overages…
- Inflation on labor only @ 3%

Mezzanine Card: Scope

- **Functionality:** Raw drift signals for up to 24 tubes are amplified, shaped and digitized by ASD chips, then routed to the TDC which stores arrival times of the leading and trailing edges of the signal.



Deliverables

Deliverable	US Interests	International Interests
ASD *design & construction*	BNL/UMich	MPI*
TDC *design & construction*	BNL/UMich	Japan, MPI*
PCB *design & construction*	Arizona, BU	-

Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	Muon system	34,084
5.1	MDT	7,692
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

** MPI willing to work with UMich on ASIC TDC (not VMM though)*
There are competing ideas though - 130nm vs 65nm

Mezz Card PCB: Labor (Arizona)

- Basis of Estimate: Labor estimated using costs incurred for Mini-1 Card and MMFE-8 Board (Phase I project)

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	Hourly Rates FY22	FY23
U. of Arizona					
Electrical Engineer 1	161,236	102.18	105.25	108.40	111.66
Engineer Associate	62,797	39.80	40.99	42.22	43.49
Engineer Tech Student	34,741	22.02	22.68	23.36	24.06

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6.1		**Muon_Arizona**					
6.6.1.1		**PCB for Mezzanine**					
		Design					
			Electrical Engineer 1	0.35			
			Engineer Associate	0.21			
			Engineer Tech Student	0.61			
		Prototype					
			Electrical Engineer 1		0.63		
			Engineer Associate		0.32		
			Engineer Tech Student		0.71		
		Production					
			Electrical Engineer 1			0.45	0.45
			Engineer Associate			0.32	0.42
			Engineer Tech Student			2.41	4.81

Mezz Card PCB: Labor (Arizona)

- Basis of Estimate: Labor estimated using costs incurred for Mini-1 Card and MMFE-8 Board (Phase I project)

Electrical Engineer 1	Lead design and layout of demonstrator, prototypes, and final board. Development of test rigging and testing all boards
Engineer Associate	Assisting with design and testing of demonstrator, prototypes, and final board design
Engineer Tech Student	Assisting with demonstrator, prototype testing, as well as mass testing of final boards

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6.1		**Muon_Arizona**					
6.6.1.1		**PCB for Mezzanine**					
		Design					
			Electrical Engineer 1	0.35			
			Engineer Associate	0.21			
			Engineer Tech Student	0.61			
		Prototype					
			Electrical Engineer 1		0.63		
			Engineer Associate		0.32		
			Engineer Tech Student		0.71		
		Production					
			Electrical Engineer 1			0.45	0.45
			Engineer Associate			0.32	0.42
			Engineer Tech Student			2.41	4.81

Mezz Card PCB: Travel (Arizona)

- <u>Travel:</u>
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
PCB for Mezzanine	**Total**					**2137.63**
	Labor	102.21	169.65	210.60	327.19	809.65
	Material	21.00	43.00	128.60	35.34	227.94
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					1064.04
	FTEs	1.17	1.66	3.18	5.68	11.69
Design	Total					
	Labor	102.21				102.21
	Material	21.00				21.00
	Travel	9.00				9.00
	CORE					
	FTEs	1.17				1.17
Prototype	Total					
	Labor		169.65			169.65
	Material		43.00			43.00
	Travel		9.00			9.00
	CORE					
	FTEs		1.66			1.66
Production	Total					
	Labor			210.60	327.19	537.80
	Material			128.60	35.34	163.94
	Travel			9.00	9.00	18.00
	CORE				1064.01	1064.04
	FTEs			3.18	5.68	8.86

Mezz Card PCB: M&S (Arizona)

- M&S Includes:
  - Design software (modelsim, altium, xilinx) ~ $7k
  - 65 1st prototypes @ $11k (FY20) and 65 prototype @11k ($FY21)
  - Test rigging @ $10k (FY21)
  - 1700 boards @ $118k (FY22) and Shipping @ $30k of final boards

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
PCB for Mezzanine	**Total**					**2137.63**
	Labor	102.21	169.65	210.60	327.19	809.65
	Material	21.00	43.00	128.60	35.34	227.94
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					1064.04
	FTEs	1.17	1.66	3.18	5.68	11.69
Design	Total					
	Labor	102.21				102.21
	Material	21.00				21.00
	Travel	9.00				9.00
	CORE					
	FTEs	1.17				1.17
Prototype	Total					
	Labor		169.65			169.65
	Material		43.00			43.00
	Travel		9.00			9.00
	CORE					
	FTEs		1.66			1.66
Production	Total					
	Labor			210.60	327.19	537.80
	Material			128.60	35.34	163.94
	Travel			9.00	9.00	18.00
	CORE				1064.01	1064.04
	FTEs			3.18	5.68	8.86

Mezz Card PCB: Construction

- <u>Basis of Estimate:</u> Scaled from low numbers of Mini-1 Cards produced (similar to the Mezz) by the ratio of low to high numbers of an MMFE-8 Board (Phase I)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
PCB for Mezzanine	**Total**					**2137.63**
	Labor	102.21	169.65	210.60	327.19	809.65
	Material	21.00	43.00	128.60	35.34	227.94
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					1064.04
	FTEs	1.17	1.66	3.18	5.68	11.69
Design	Total					
	Labor	102.21				102.21
	Material	21.00				21.00
	Travel	9.00				9.00
	CORE					
	FTEs	1.17				1.17
Prototype	Total					
	Labor		169.65			169.65
	Material		43.00			43.00
	Travel		9.00			9.00
	CORE					
	FTEs		1.66			1.66
Production	Total					
	Labor			210.60	327.19	537.80
	Material			128.60	35.34	163.94
	Travel			9.00	9.00	18.00
	CORE				$\boxed{1064.01}$	1064.04
	FTEs			3.18	5.68	8.86

Mezz Card PCB: Construction

6.6.x.1 MEZZ CORE COSTS						
PRODUCTION COSTS						
	Items	**# Boards**	**Cost/Board ($)**	**Flat Cost - NRE ($)**	**Total Cost (k$)**	
PCB (Final)					**1064.04**	
	Fabrication	15502	13.99		216.92	
	Assembly	15502	37.53		581.72	
	Parts	15502	17.12		265.39	
PCB (Pre-production)					118.26	
	Fabrication	1723	13.99		24.11	
	Assembly	1723	37.53		64.66	
	Parts	1723	17.12		29.50	
PCB (Prototypes)					10.88	
	Fabrication	65	38.68		2.51	
	Assembly	65	111.58		7.25	
	Parts	65	17.12		1.11	
Basis of Estimate						
	Steps	**# Boards**	**Cost/Board ($)**	**Flat Cost - NRE ($)**	**Total Cost**	**Price per Board**
MINI1 Board (Phase I)						
board similar to mezz	Fabrication	20	162.13	625.00	3867.60	193.38
	Assembly	20	145.00	250.00	3150.00	157.50
MMFE8 (Small Amount)	Fabrication	10	360.00		3600.00	360.00
used for scaling	Assembly	5	282.30		1411.50	282.30
MMFE8 (Dozens)	Fabrication	50	72.00		3600.00	72.00
used for scaling	Assembly	50	200.00		10000.00	200.00
MMFE8 (1000's)	Fabrication	5000	26.05		130250.00	26.05
used for scaling	Assembly	5000	67.26		336300.00	67.26
						Ratio
					Fabrication	
					"50/10"	0.20
					"5000/10"	0.07
					Assembly	
					"50/5"	0.71
					"5000/5"	0.24

Mezz-Like PCB

Not-like Mezz PCB used to estimate cost scaling

Mezz Card PCB: Construction

6.6.x.1 MEZZ CORE COSTS

PRODUCTION COSTS

	Items	# Boards	Cost/Board ($)	Flat Cost - NRE ($)	Total Cost (k$)
PCB (Final)					**1064.04**
	Fabrication	15502	13.99		216.92
	Assembly	15502	37.53		581.72
	Parts	15502	17.12		265.39
PCB (Pre-production)					118.26
	Fabrication	1723	13.99		24.11
	Assembly	1723	37.53		64.66
	Parts	1723	17.12		29.50
PCB (Prototypes)					10.88
	Fabrication	65	38.68		2.51
	Assembly	65	111.58		7.25
	Parts	65	17.12		1.11

Basis of Estimate

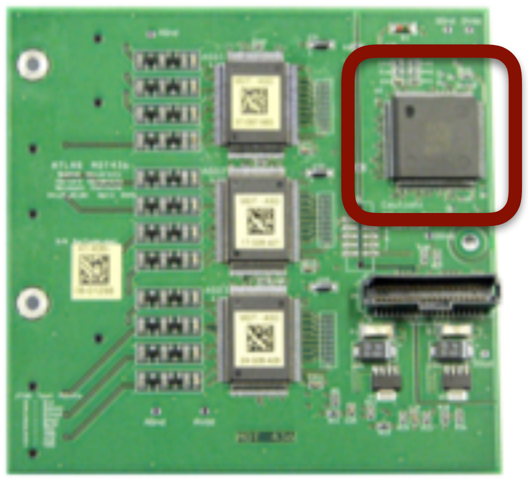
		Steps	# Boards	Cost/Board ($)	Flat Cost - NRE ($)	Total Cost	Price per Board
Mezz-Like PCB	**MINI1 Board (Phase I)**						
	board similar to mezz	Fabrication	20	162.13	625.00	3867.60	193.38
		Assembly	20	145.00	250.00	3150.00	157.50
Not-like Mezz PCB used to estimate cost scaling	**MMFE8 (Small Amount)**	Fabrication	10	360.00		3600.00	360.00
	used for scaling	Assembly	5	282.30		1411.50	282.30
	MMFE8 (Dozens)	Fabrication	50	72.00		3600.00	72.00
	used for scaling	Assembly	50	200.00		10000.00	200.00
	MMFE8 (1000's)	Fabrication	5000	26.05		130250.00	26.05
	used for scaling	Assembly	5000	67.26		336300.00	67.26

	Ratio
Fabrication	
"50/10"	0.20
"5000/10"	0.07
Assembly	
"50/5"	0.71
"5000/5"	0.24

13.99 ➜ 0.07 * 193.38
37.53 ➜ 0.24 * 157.50

Mezz Card TDC: Scope

- <u>Functionality:</u> TDC produces arrival times of leading & trailing edges of tube signals, as well as an identifier word for the corresponding tube, and sends to the CSM



Deliverables

Deliverable	US Interests	International Interests
TDC *design & construction*	**BNL/UMich**	**Japan, MPI***

** MPI willing to work with UMich on ASIC TDC (not VMM though)*
There are competing ideas though - 130nm vs 65nm

Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

Mezz Card TDC: Labor (Michigan)

- <u>Basis of Estimate:</u> Labor estimated using costs incurred for Phase I Trigger Data Serializer Chip (TDS) for the NSW

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	FY22	FY23
		Hourly Rates			
Michigan					
Sr Electronics Engineer	120,000	76.05	78.33	80.68	83.10
Jr Electronics Engineer	90,000	57.04	58.75	60.51	62.32
Electronics Technician	65,000	41.19	42.43	43.70	45.01
Engineering Student	50,000	31.69	32.64	33.62	34.62
Mechanical Engineer	120,000	76.05	78.33	80.68	83.10
Mechanical Technician	80,000	50.70	52.22	53.79	55.40

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.3		Muon_Michigan					
6.6.3.2		TDC					
		Design					
			Sr Electronics Engineer	0.50			
			Jr Electronics Engineer	0.50			
			Electronics Technician				
			Engineering Student	0.50			
		Prototype					
			Sr Electronics Engineer	0.50	1.00		
			Jr Electronics Engineer	0.50	1.00		
			Electronics Technician				
			Engineering Student	0.50	1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Jr Electronics Engineer			1.00	1.00
			Electronics Technician				
			Engineering Student			1.00	1.00

Mezz Card TDC: Labor (Michigan)

- <u>Basis of Estimate:</u> Labor estimated using costs incurred for Phase I Trigger Data Serializer Chip (TDS) for the NSW

Sr Electronics Engineer	**Focusing on the design for the two prototype runs and the final production run**
Jr Electronics Engineer	**Provide help with the design but focus more on the design of test fixtures and the readout system**
Engineering Student	**Perform simulation studies and chip tests**

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.3		Muon_Michigan					
6.6.3.2		TDC					
		Design					
			Sr Electronics Engineer	0.50			
			Jr Electronics Engineer	0.50			
			Electronics Technician				
			Engineering Student	0.50			
		Prototype					
			Sr Electronics Engineer	0.50	1.00		
			Jr Electronics Engineer	0.50	1.00		
			Electronics Technician				
			Engineering Student	0.50	1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Jr Electronics Engineer			1.00	1.00
			Electronics Technician				
			Engineering Student			1.00	1.00

Mezz Card TDC: M&S (UMich)

- Travel:
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23			
TDC	**Total**							**2245.26**
	Labor	292.63	301.41	310.45	319.77			1224.26
	Material	155.00	145.00	25.00	10.00			335.00
	Travel	9.00	9.00	9.00	9.00			36.00
	CORE	0.00	0.00	650.00	0.00			650.00
	FTEs	3.00	3.00	3.00	3.00			12.00
Design	Total							0.00
	Labor	146.32						146.32
	Material							0.00
	Travel	9.00						9.00
	CORE							0.00
	FTEs	1.50						1.50
Prototype	Total							0.00
	Labor	146.32	301.41					447.73
	Material	155.00	145.00					300.00
	Travel		9.00					9.00
	CORE							0.00
	FTEs	1.50	3.00					4.50
Production	Total							0.00
	Labor			310.45	319.77			630.22
	Material			25.00	10.00			35.00
	Travel			9.00	9.00			18.00
	CORE			650.00				650.00
	FTEs			3.00	3.00			6.00

Mezz Card TDC: M&S (UMich)

- Cadence software license fee is $5k/year
- Chip shipping $5k
- Two test fixtures run in parallel for production

TDC Prototype			**150.000**
MOSIS Submission	1	100000	100.000
Packaging NRE (wire-bonded)	1	40000	40.000
Test Fixtures	1	10000	10.000

Description	AY k$	FY20	FY21	FY22	FY23			
TDC	**Total**							**2245.26**
	Labor	292.63	301.41	310.45	319.77			1224.26
	Material	155.00	145.00	25.00	10.00			335.00
	Travel	9.00	9.00	9.00	9.00			36.00
	CORE	0.00	0.00	650.00	0.00			650.00
	FTEs	3.00	3.00	3.00	3.00			12.00
Design	Total							0.00
	Labor	146.32						146.32
	Material							0.00
	Travel	9.00						9.00
	CORE							0.00
	FTEs	1.50						1.50
Prototype	Total							0.00
	Labor	146.32	301.41					447.73
	Materia	$\boxed{155.00}$	$\boxed{145.00}$					300.00
	Travel		9.00					9.00
	CORE							0.00
	FTEs	1.50	3.00					4.50
Production	Total							0.00
	Labor			310.45	319.77			630.22
	Material			$\boxed{25.00}$	$\boxed{10.00}$			35.00
	Travel			9.00	9.00			18.00
	CORE			650.00				650.00
	FTEs			3.00	3.00			6.00

Mezz Card TDC: Construction (UMich)

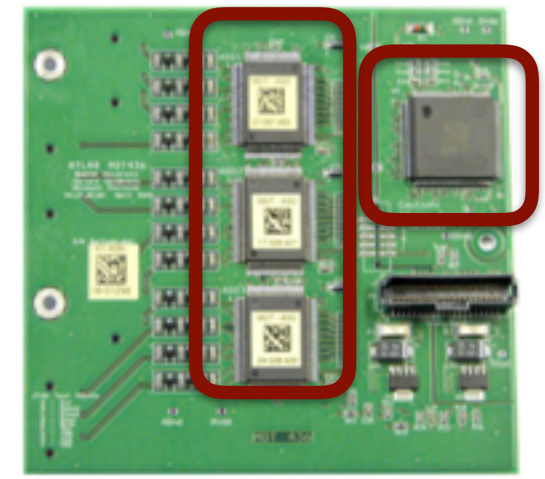
- Chips/Wafers: Direct quote from MOSIS ($1.2M total, $600k assuming sharing submission with at least one other project)
- Packaging: Direct quote from I2C
- Test Fixtures: Based on Phase I experience for PCB and DAQ system

Components	Count/Board	Cost/Item ($)	Total (k$)
TDC Production			**670.000**
MOSIS Submission	1	600000	600.000
Packaging NRE	1	50000	50.000
Test Fixtures	2	10000	20.000

Description	AY k$	FY20	FY21	FY22	FY23			
TDC	**Total**							**2245.26**
	Labor	292.63	301.41	310.45	319.77			1224.26
	Material	155.00	145.00	25.00	10.00			335.00
	Travel	9.00	9.00	9.00	9.00			36.00
	CORE	0.00	0.00	650.00	0.00			650.00
	FTEs	3.00	3.00	3.00	3.00			12.00
Design	Total							0.00
	Labor	146.32						146.32
	Material							0.00
	Travel	9.00						9.00
	CORE							0.00
	FTEs	1.50						1.50
Prototype	Total							0.00
	Labor	146.32	301.41					447.73
	Material	155.00	145.00					300.00
	Travel		9.00					9.00
	CORE							0.00
	FTEs	1.50	3.00					4.50
Production	Total							0.00
	Labor			310.45	319.77			630.22
	Material			25.00	10.00			35.00
	Travel			9.00	9.00			18.00
	CORE			$\boxed{650.00}$				650.00
	FTEs			3.00	3.00			6.00

Mezz Card VMM: Scope

- <u>Functionality:</u> Provides both TDC and ASD functionality
  - ASD (amplified, shaper, discriminator)
  - Technology: GF 130 nm CMOS 8RF-DM (Formerly IBM 8RFDM)
  - Need 350,000 channels MDT (24 channels/VMM) + <u>384,000 sTGC</u> (64 ch/VMM)+10% and a yield of 130 VMM per 12” wafer. Total of 175 wafers in production.



Deliverables

Deliverable	US Interests	International Interests
TDC *design & construction*	BNL/UMich	Japan, MPI*
64 ch VMM (sTGC)	BNL	-

** MPI willing to work with UMich on ASIC TDC (not VMM though)*
There are competing ideas though - 130nm vs 65nm

Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	Muon system	34,084
5.1	MDT	7,692
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650
5.3	TGC	4,436
5.3.1	On-detector electronics (PS)	2,136
5.3.2	sTGC on BW inner ring	2,300

Mezz Card VMM: Labor (BNL)

- <u>Basis of Estimate:</u> Estimated design and testing for modified 24 channel VMM from experience with current VMM (Phase I), using rates at BNL (FY16, burdened at 34%)

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	Hourly Rates FY22	FY23
SCI1	217,400	137.77	141.91	146.16	150.55
Tech Student 1	67,488	42.77	44.05	45.37	46.74
Tech Student 2	67,488	42.77	44.05	45.37	46.74

Description	FTEs	FY20	FY21	FY22	FY23
Muon					
TDC					
Design					
	SCI1	1.00			
	Tech Student 1	1.00			
	Tech Student 2	1.00			
Prototype					
	SCI1		1.00		
	Tech Student 1		1.00		
	Tech Student 2		1.00		
Production					
	SCI1			1.00	1.00
	Tech Student 1			1.00	1.00
	Tech Student 2			1.00	1.00

Mezz Card VMM: Travel (BNL)

- Travel:
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
TDC	**Total**					**2778.08**
	Labor	198.30	408.50	420.76	433.38	1460.93
	Material	0.00	376.00	0.00	0.00	376.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					905.15
	FTEs	1.50	3.00	3.00	3.00	10.50
Design	Total					0.00
	Labor	198.30				198.30
	Material					0.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	1.50				1.50
Prototype	Total					0.00
	Labor		408.50			408.50
	Material		376.00			376.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		3.00			3.00
Production	Total					0.00
	Labor			420.76	433.38	854.13
	Material					0.00
	Travel			9.00	9.00	18.00
	CORE				905.15	905.15
	FTEs			3.00	3.00	6.00

Mezz Card VMM: M&S (BNL)

- M&S: prototype costs
  - Based on FY16 quotes for 64ch VMM
  - Two spins for custom runs, if first acceptable no second needed

Components	Count/Board	Cost/Item ($)	Total (k$)
VMM Prototype			**376.000**
Prototype Mask Set	1	341000	341.000
Packaging NRE (includes up to 1000 devices)	1	21000	21.000
Test Boards	1	14000	14.000

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
TDC	**Total**					**2778.08**
	Labor	198.30	408.50	420.76	433.38	1460.93
	Material	0.00	376.00	0.00	0.00	376.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					905.15
	FTEs	1.50	3.00	3.00	3.00	10.50
Design	Total					0.00
	Labor	198.30				198.30
	Material					0.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	1.50				1.50
Prototype	Total					0.00
	Labor		408.50			408.50
	Material		$\boxed{376.00}$			376.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		3.00			3.00
Production	Total					0.00
	Labor			420.76	433.38	854.13
	Material					0.00
	Travel			9.00	9.00	18.00
	CORE				905.15	905.15
	FTEs			3.00	3.00	6.00

Mezz Card VMM: Construction (BNL)

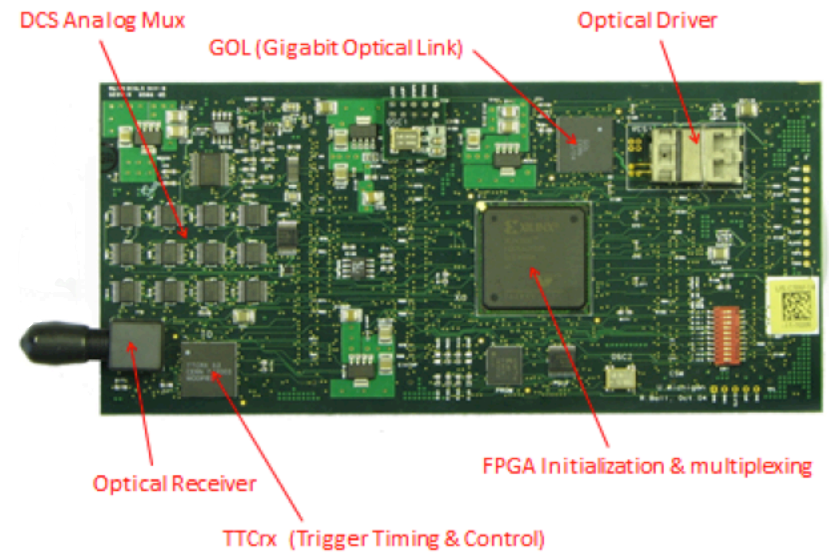
PRODUCTION COSTS			
Components	**Count/Board**	**Cost/Item ($)**	**Total (k$)**
VMM Production			**905.150**
Production Mask Set	1	341000	341.000
Packaging NRE	1	21000	21.000
Packaging Wafer 175 @ 2230 each	175	2230	390.250
Packaging per Device 23000 @ 2.30	23000	2.3	52.900
Testing	1	100000	100.000

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
TDC	**Total**					**2778.08**
	Labor	198.30	408.50	420.76	433.38	1460.93
	Material	0.00	376.00	0.00	0.00	376.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE					905.15
	FTEs	1.50	3.00	3.00	3.00	10.50
Design	Total					0.00
	Labor	198.30				198.30
	Material					0.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	1.50				1.50
Prototype	Total					0.00
	Labor		408.50			408.50
	Material		376.00			376.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		3.00			3.00
Production	Total					0.00
	Labor			420.76	433.38	854.13
	Material					0.00
	Travel			9.00	9.00	18.00
	CORE				905.15	905.15
	FTEs			3.00	3.00	6.00

CSM: Scope

<u>Functionality:</u>

- One MDT chamber, up to 18 mezzanines, are controlled by a local processor board (CSM)
- The CSM broadcasts the TTC signals to the TDCs, and collects data from the TDCs
- At the CSM, data are formatted, stored, and sent via optical link to the Hit Extraction Board (HEB)



Deliverables

Deliverable	US Interests	International Interests
CSM *design & construction*	**UMich**	**-**

CORE Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

CSM: Labor (Michigan)

- <u>Basis of Estimate:</u> Expected personnel levels based on previous experience developing CSM at U-M

<u>Previous CSM Development Team at U-M</u>

- ➡ Jay Chapman (Sr Engineer equivalent) - CSM Leader/Firmware Design
- ➡ Pietro Binchi (Engineer) - Board design, left midway through development
- ➡ Bob Ball (Engineer) - CSM Firware, Board design, hired after Pietro left
- ➡ Tiesheng Dai (Engineer) - Test fixtures for MiniDAQ, test and debug
- ➡ Jon Ameel (Engineer) - Production, parts, testing on-site CERN
- ➡ Jeff Gregor and Tuan Anh Bui (Students) - Test and debug, some development

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.3.3		CSM					
		Design					
			Sr Electronics Engineer	0.50			
			Jr Electronics Engineer	0.50			
			Electronics Technician	0.50			
			Engineering Student	0.50			
		Prototype					
			Sr Electronics Engineer	0.50	1.00		
			Jr Electronics Engineer	0.50	1.00		
			Electronics Technician	0.50	1.00		
			Engineering Student	0.50	1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Jr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00
			Engineering Student			1.00	1.00

CSM: Labor (Michigan)

- <u>Basis of Estimate:</u> Expected personnel levels based on previous experience developing CSM at U-M

Sr Electronics Engineer	Lead on the CSM firmware and PCB design for two prototypes and production - for both new and legacy mezzanine electronics
Jr Electronics Engineer	Focus on modifications of new CSM to handle legacy mezzanine, test fixtures, and readout system
Engineering Technician	Lead development of movable test stations to test MDT chambers on surface, testing all new CSM's (> 1000)
Engineering Student	Assist with testing new CSM's, testing prototypes

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.3.3		**CSM**					
		Design					
			Sr Electronics Engineer	0.50			
			Jr Electronics Engineer	0.50			
			Electronics Technician	0.50			
			Engineering Student	0.50			
		Prototype					
			Sr Electronics Engineer	0.50	1.00		
			Jr Electronics Engineer	0.50	1.00		
			Electronics Technician	0.50	1.00		
			Engineering Student	0.50	1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Jr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00
			Engineering Student			1.00	1.00

CSM: Labor (Michigan)

- **Basis of Estimate:** Expected personnel levels based on previous experience developing CSM at U-M

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	Hourly Rates FY22	FY23
Michigan					
Sr Electronics Engineer	120,000	76.05	78.33	80.68	83.10
Jr Electronics Engineer	90,000	57.04	58.75	60.51	62.32
Electronics Technician	65,000	41.19	42.43	43.70	45.01
Engineering Student	50,000	31.69	32.64	33.62	34.62
Mechanical Engineer	120,000	76.05	78.33	80.68	83.10
Mechanical Technician	80,000	50.70	52.22	53.79	55.40

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		**Muon**					
6.6.3.3		**CSM**					
		Design					
			Sr Electronics Engineer	0.50			
			Jr Electronics Engineer	0.50			
			Electronics Technician	0.50			
			Engineering Student	0.50			
		Prototype					
			Sr Electronics Engineer	0.50	1.00		
			Jr Electronics Engineer	0.50	1.00		
			Electronics Technician	0.50	1.00		
			Engineering Student	0.50	1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Jr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00
			Engineering Student			1.00	1.00

CSM: Travel (Michigan)

- Travel:
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
CSM	**Total**	394.79	385.76	397.07	1690.99	**2868.61**
	Labor	365.79	376.76	388.07	399.71	1530.33
	Material	20.00	0.00	0.00	35.00	55.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE				1247.28	1247.28
	FTEs	4.00	4.00	4.00	4.00	16.00
Design	Total					0.00
	Labor	182.90				182.90
	Material					0.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.00				2.00
Prototype	Total					0.00
	Labor	182.90	376.76			559.66
	Material	20.00				20.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs	2.00	4.00			6.00
Production	Total					0.00
	Labor			388.07	399.71	787.78
	Material				35.00	35.00
	Travel			9.00	9.00	18.00
	CORE				**1247.28**	1247.28
	FTEs			4.00	4.00	8.00

CSM: M&S (Michigan)

- M&S
  - Two prototypes @ $10k (based on Phase I router costs)
  - $35k shipping - scaled from 200X costs?

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
CSM	**Total**	394.79	385.76	397.07	1690.99	**2868.61**
	Labor	365.79	376.76	388.07	399.71	1530.33
	Material	20.00	0.00	0.00	35.00	55.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE				1247.28	1247.28
	FTEs	4.00	4.00	4.00	4.00	16.00
Design	Total					0.00
	Labor	182.90				182.90
	Material					0.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.00				2.00
Prototype	Total					0.00
	Labor	182.90	376.76			559.66
	Material	20.00				20.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs	2.00	4.00			6.00
Production	Total					0.00
	Labor			388.07	399.71	787.78
	Material				35.00	35.00
	Travel			9.00	9.00	18.00
	CORE				**1247.28**	1247.28
	FTEs			4.00	4.00	8.00

CSM: Construction (Michigan)

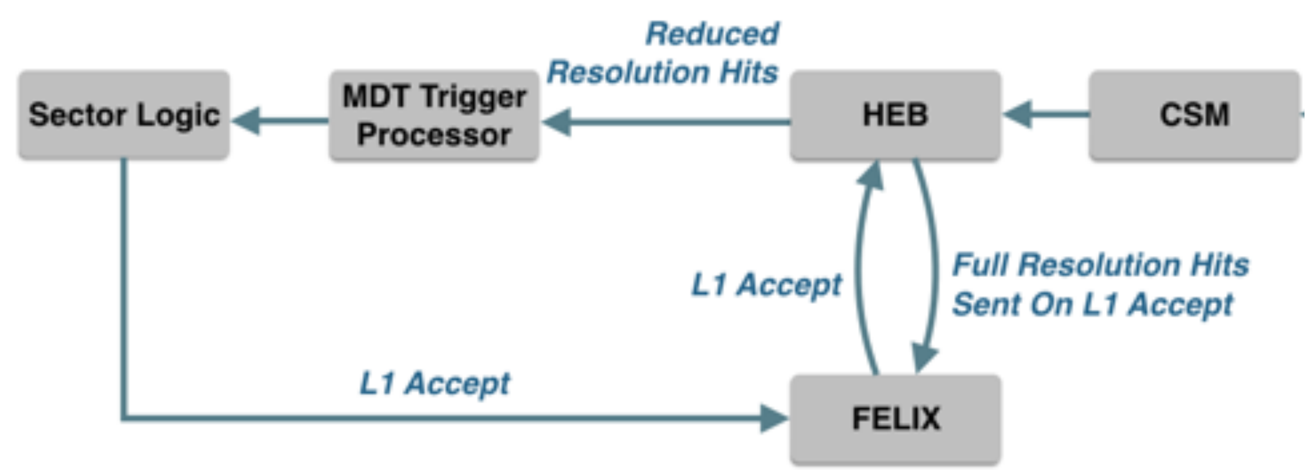
- **Starting point is a baseline Phase II design, including new FPGA and replacing some previous electronics with the GBT system of chips**
- **Assuming similar construction costs to the current ATLAS CSMs, accounting for new components, inflation, and exchange rates.**
- **Current CSM Construction costs taken from the 2003 ATLAS AGREEMENT 201-05 *"Production of CSM electronics for the ATLAS Muons Detector"***
- **New Components, such as the GBT chips, are taken either from recent listed costs or from estimates of the developer/manufacturer (CERN for GBT)**

Components	Count/Board	Cost/Item ($)	Basis of Estimate
CSM			
FPGA	1	279.323	Cost of modern FPGA matched to required performance
PROM	1	15.802	Scaled costs from 2003, plus inflation and exchange rate
GBLD, laser diode, housing	1	105.154	Current Cost estimates by CERN
GBT-SCA	1	33.649	Current Cost estimates by CERN
Misc Parts	1	175.015	Scaled costs from 2003, plus inflation and exchange rate
GBTx	1	175.000	Current Cost estimates by CERN
Fabrication and Assembly	1	157.400	Scaled costs from 2003, plus inflation and exchange rate
Cost per Board		**941.343**	
Basis of Number of Boards	**# Boards**	**Total Cost (k$)**	
624 chambers + 546 in end cap leads to 608, 510 CSM respectively. -64 CSM from NSW and +22 for new chambers. 10% override, 85% yield	**1325**	**1,247,279**	

HEB: Scope

Functionality:

- Receive data from front-end boards.
- Provide data buffering for L0/L1.
- Deliver low-latency, low-granularity signals to hardware trigger.
- Interface with network-based trigger/DAQ system (FELIX).



Deliverables

Deliverable	US Interests	International Interests
HEB *design & construction*	Illinois	maybe MPI

CORE Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

HEB: Labor (Illinois)

- <u>Basis of Estimate:</u> Rates based on available manpower available at Illinois for current engineers/technicians. Note additional physicist manpower includes V.Martinez Outschoorn who has 5 years of dedicated experience on MDTs.

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	Hourly Rates FY22	FY23
Illinois					
Sr Electronics Engineer	183,890	116.54	120.03	123.63	127.34
Electronics Technician	97,913	62.05	63.91	65.83	67.80

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.4		Muon_Illinois					
6.6.4.4		HEB					
		Design					
			Sr Electronics Engineer	1.00			
			Electronics Technician	1.00			
		Prototype					
			Sr Electronics Engineer		1.00		
			Electronics Technician		1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00

HEB: Labor (Illinois)

- <u>Basis of Estimate:</u> Rates based on available manpower available at Illinois for current engineers/technicians. Note additional physicist manpower includes V.Martinez Outschoorn who has 5 years of dedicated experience on MDTs.

Sr Electronics Engineer ***(50% Mike Kasten, 50% Todd Moore)***	**Leading board design, firmware development, testing of fixtures, debugging and production**
Engineering Technician ***(Allison Sibert)***	**Assist in testing and debugging as well as assembly for production**

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.4		Muon_Illinois					
6.6.4.4		HEB					
		Design					
			Sr Electronics Engineer	1.00			
			Electronics Technician	1.00			
		Prototype					
			Sr Electronics Engineer		1.00		
			Electronics Technician		1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00

HEB: Labor (Illinois)

- <u>Basis of Estimate:</u> Rates based on available manpower available at Illinois for current engineers/technicians
    - FY17-18: Simulations & implementation on evaluation boards - detail system requirements and provide design.
    - FY 19-20: Design of Mezzanine card - Carrier & RTM purchased from other ATLAS projects or commercially available products.
    - FY 21: Prototype Mezzanine card, debugging & testing. Continue to develop firmware in parallel.
    - FY 22-23: Production phase.

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.4		Muon_Illinois					
6.6.4.4		HEB					
		Design					
			Sr Electronics Engineer	1.00			
			Electronics Technician	1.00			
		Prototype					
			Sr Electronics Engineer		1.00		
			Electronics Technician		1.00		
		Production					
			Sr Electronics Engineer			1.00	1.00
			Electronics Technician			1.00	1.00

HEB: Travel (Illinois)

- **Travel:**
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
HEB	**Total**					**2153.85**
	Labor	317.17	326.69	336.49	346.58	1326.93
	Material	10.00	10.00	2.00	2.00	24.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE				766.92	766.92
	FTEs	2.00	2.00	2.00	2.00	8.00
Design	Total					0.00
	Labor	317.17				317.17
	Material	10.00				10.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.00				2.00
Prototype	Total					0.00
	Labor		326.69			326.69
	Material		10.00			10.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		2.00			2.00
Production	Total					0.00
	Labor			336.49	346.58	683.07
	Material			2.00	2.00	4.00
	Travel			9.00	9.00	18.00
	CORE				766.92	766.92
	FTEs			2.00	2.00	4.00

HEB: M&S (Illinois)

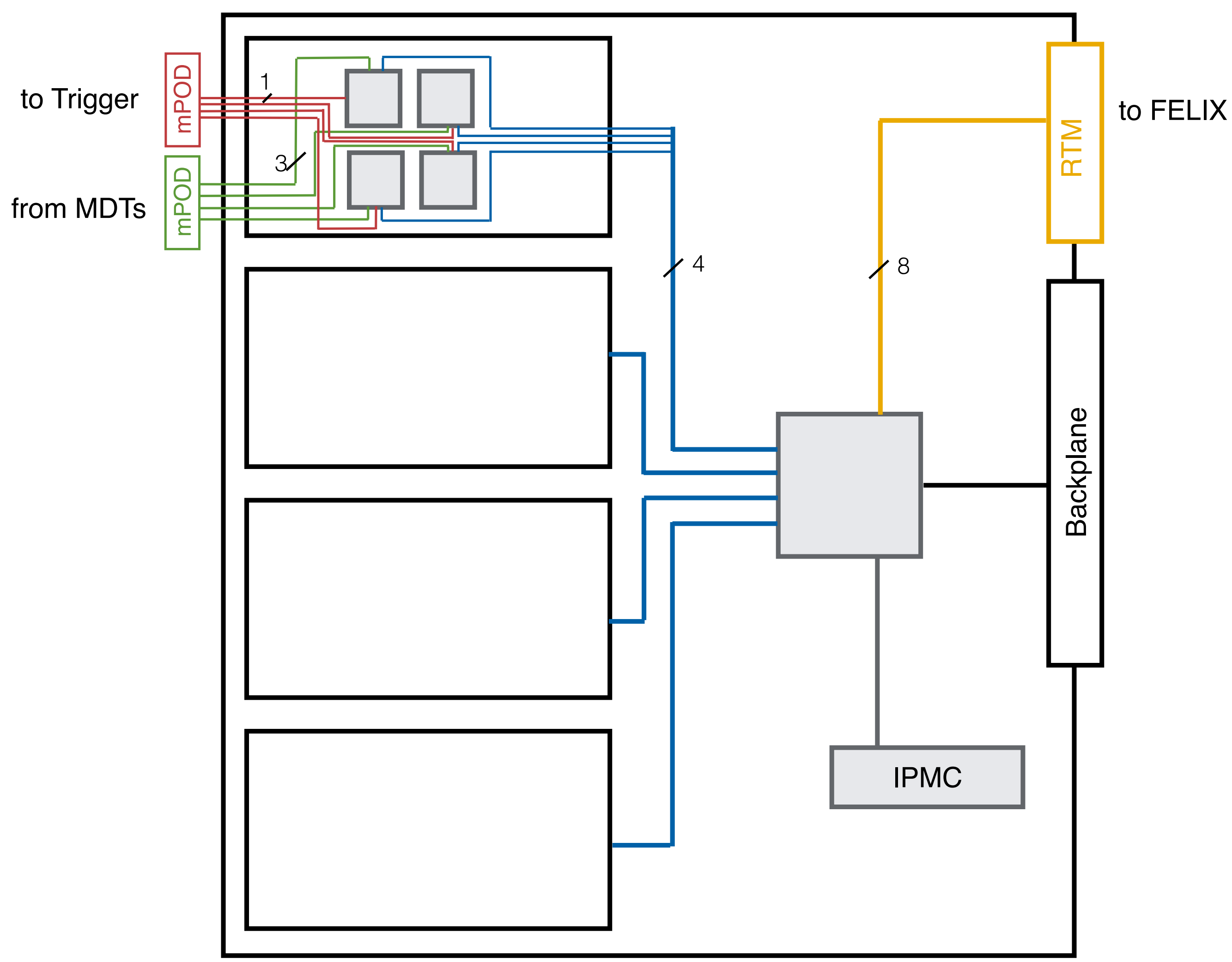
- M&S
  - Two Prototypes: mainly costs associated with mezzanine, carrier cards, and a transition module from ATLAS - to be tested on ATCA crate at Illinois
  - Costs based on test stand recently purchased at Illinois for Phase I project
  - Other incidental supplies requested

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
HEB	**Total**					**2153.85**
	Labor	317.17	326.69	336.49	346.58	1326.93
	Material	10.00	10.00	2.00	2.00	24.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE				766.92	766.92
	FTEs	2.00	2.00	2.00	2.00	8.00
Design	Total					0.00
	Labor	317.17				317.17
	Material	10.00				10.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.00				2.00
Prototype	Total					0.00
	Labor		326.69			326.69
	Material		10.00			10.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		2.00			2.00
Production	Total					0.00
	Labor			336.49	346.58	683.07
	Material			2.00	2.00	4.00
	Travel			9.00	9.00	18.00
	CORE				766.92	766.92
	FTEs			2.00	2.00	4.00

HEB: Construction (Illinois)

Possible Implementation in ATCA platform

- 24 ATCA blades (+ overage)
  - 4 Mezzanine cards, each process 12 input channels
  - 1 Carrier card
  - 1 RTM
- Full system with ~1100 input channels fits in 2 ATCA crates - compact



HEB: Construction (Illinois)

Components	Count/Board	Cost/Item ($)	Unit Cost ($)	Total (k$)
HEB				**766.922**
ATCA System	2		**15000**	30
include Chassis - Shelf, Shelf Manager, Power Supply				
Mezzanine Card	106		**3885**	411.81
Kintex 7 FPGA (8 GTX, XC7K160T-2FBG676)	4	340	1360	
miniPod Rx (12ch)	1	250	250	
miniPod Tx (12ch)	1	375	375	
other components	1	500	500	
PCB, assembly	1	1400	1400	
ATCA Blades	26		**6886**	179.036
Kintex 7 FPGA (8 GTX, XC7K160T-2FBG676)	1	4886	4886	
Front Panels	1	200	200	
Other components	1	500	500	
PCB, Assembly	1	1300	1300	
Transition Module	26		**3000**	78
miniPod Rx (L0/L1)	1	250	250	
QSFPs (FELIX)	3	250	750	
Rear Panels	1	200	200	
Other Components	1	500	500	
PCB, Assembly	1	1300	1300	
Adaptors for miniPod Connections	238		**202**	48.076
MTP-MTP Bulkhead adapter (12 ch)	1	22	22	
Cable with MTP, 6 inches (12 ch)	1	180	180	
Additional Modules	2		**10000**	20
for TTC, DCS for each partition				

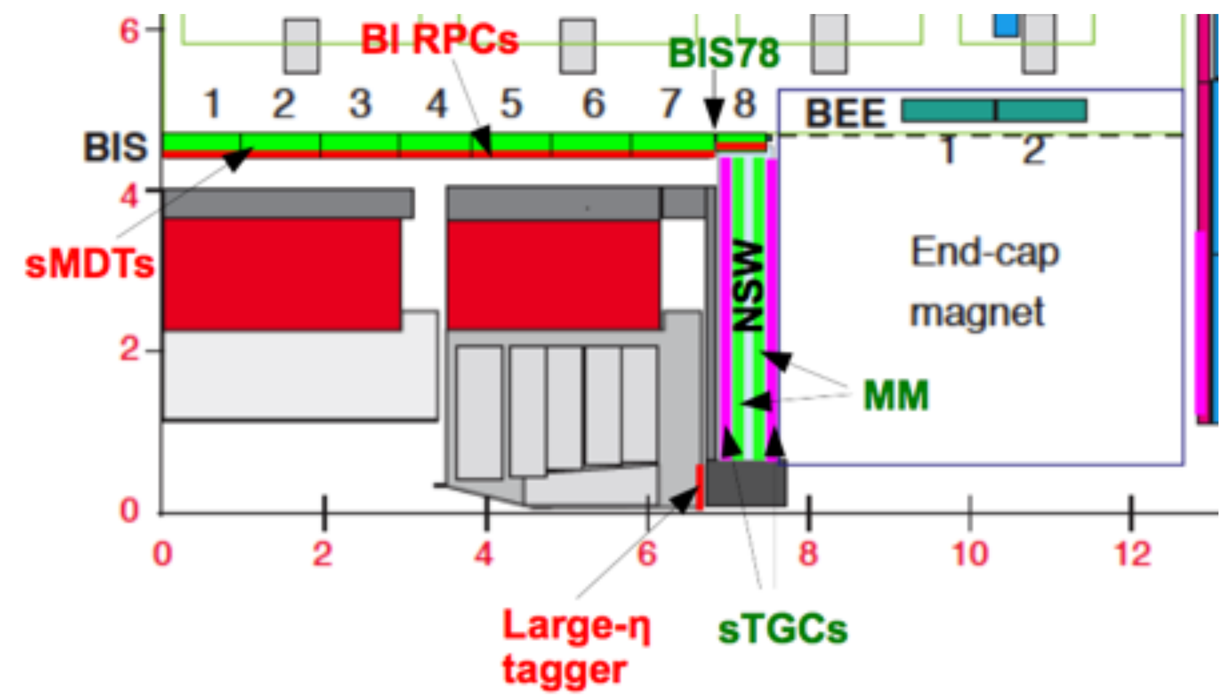
HEB: M&S (Illinois)

Components	Count/Board	Cost/Item ($)	Unit Cost ($)	Total (k$)
HEB				**766.922**
ATCA System	2		**15000**	30
include Chassis - Shelf, Shelf Manager, Power Supply				
Mezzanine Card	106		3885	411.81
Kintex 7 FPGA (8 GTX, XC7K160T-2FBG676)	4	340	1360	

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
HEB	**Total**					**2153.85**
	Labor	317.17	326.69	336.49	346.58	1326.93
	Material	10.00	10.00	2.00	2.00	24.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE				766.92	766.92
	FTEs	2.00	2.00	2.00	2.00	8.00
Design	Total					0.00
	Labor	317.17				317.17
	Material	10.00				10.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.00				2.00
Prototype	Total					0.00
	Labor		326.69			326.69
	Material		10.00			10.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		2.00			2.00
Production	Total					0.00
	Labor			336.49	346.58	683.07
	Material			2.00	2.00	4.00
	Travel			9.00	9.00	18.00
	CORE				766.92	766.92
	FTEs			2.00	2.00	4.00

sMDT: Scope

- Replacing current MDT’s with sMDT’s to make room for RPC’s - maintains trigger efficiency after RPC gain drop in current system
- MPI constructing 50%, utilize existing infrastructure at UMich and tooling already developed at MPI to construct other 50%



Deliverables		
Deliverable	**US Interests**	**International Interests**
sMDT *design & construction*	**UMich**	**MPI (50%)**

Strong desire for US contribution by ATLAS Muon Project Leadership and MPI

CORE Costs from Scoping Doc

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	**MDT**	**7,692**
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

sMDT: Labor (UMich)

- Basis of Estimate: Engineers at UMich who took part on previous MDT construction (salary and people power)

Inst/Position	Base Cost - 2016 (k$/year – burdened)	FY20	FY21	Hourly Rates FY22	FY23
Michigan					
Sr Electronics Engineer	120,000	76.05	78.33	80.68	83.10
Jr Electronics Engineer	90,000	57.04	58.75	60.51	62.32
Electronics Technician	65,000	41.19	42.43	43.70	45.01
Engineering Student	50,000	31.69	32.64	33.62	34.62
Mechanical Engineer	120,000	76.05	78.33	80.68	83.10
Mechanical Technician	80,000	50.70	52.22	53.79	55.40

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		Muon					
6.6.3.5		sMDT					
		Tooling Construction					
			Jr Electronics Engineer	0.50	0.50		
			Electronics Technician				
			Engineering Student				
			Mechanical Engineer	1.00	0.50		
			Mechanical Technician	1.00	0.50		
		Tube Construction					
			Jr Electronics Engineer				
			Electronics Technician				
			Engineering Student		1.00	1.50	
			Mechanical Engineer				
			Mechanical Technician		0.50	1.00	
		Chamber Construction					
			Jr Electronics Engineer		0.50	0.25	0.25
			Electronics Technician				
			Engineering Student		0.50	0.50	0.50
			Mechanical Engineer		0.50	0.25	0.25
			Mechanical Technician		0.50	2.00	2.00

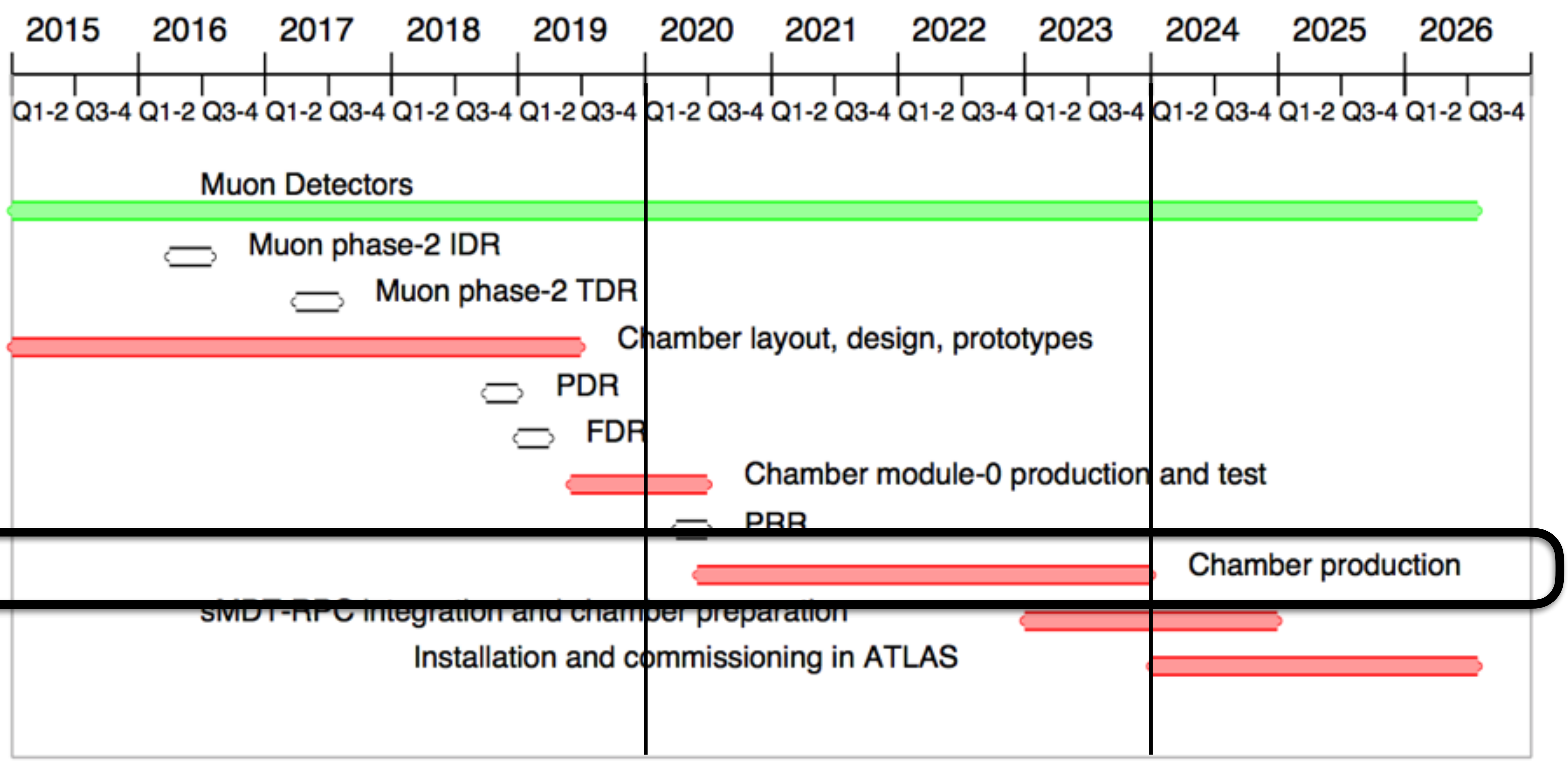
sMDT: Labor (UMich)

- <u>Basis of Estimate:</u> Engineers at UMich who took part on previous MDT construction (salary and people power)

Jr Electronics Engineer	**Develop automated systems for tube and chamber production facilities and programs**
Mechanical Engineer	**Handle mechanical problems, tuning and precision testing; also take care of procurement, quality checks of the components, parts, shipping arrangement/ boxing and and handle all mechanical issues (there will a lot).**
Mechanical Technician	**Tube and chamber construction**

WBS	Tag	Description	FTEs	FY20	FY21	FY22	FY23
6.6		**Muon**					
6.6.3.5		**sMDT**					
		Tooling Construction					
			Jr Electronics Engineer	0.50	0.50		
			Electronics Technician				
			Engineering Student				
			Mechanical Engineer	1.00	0.50		
			Mechanical Technician	1.00	0.50		
		Tube Construction					
			Jr Electronics Engineer				
			Electronics Technician				
			Engineering Student		1.00	1.50	
			Mechanical Engineer				
			Mechanical Technician		0.50	1.00	
		Chamber Construction					
			Jr Electronics Engineer		0.50	0.25	0.25
			Electronics Technician				
			Engineering Student		0.50	0.50	0.50
			Mechanical Engineer		0.50	0.25	0.25
			Mechanical Technician		0.50	2.00	2.00

ATLAS Muon Schedule



sMDT: Travel (UMich)

- Travel:
  - 2 trips to CERN, $3.5k each including overhead (Muon/upgrade week)
  - 1 trip domestic, $2k each including overhead (Collaboration, BNL, etc.)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
sMDT	**Total**					**3012.28**
	Labor	275.75	469.51	477.17	292.10	1514.52
	Material	400.00	0.00	0.00	0.00	400.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE		353.92	353.92	353.92	1061.76
	FTEs	2.50	5.00	5.50	3.00	16.00
Tooling Construction	Total					0.00
	Labor	275.75	168.09			443.84
	Material	400.00				400.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.50	1.50			4.00
Tube Construction	Total					0.00
	Labor		104.33	185.08		289.41
	Material					0.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		1.50	2.50		4.00
Chamber Construction	Total					0.00
	Labor		197.08	292.10	292.10	781.27
	Material					0.00
	Travel			9.00	9.00	18.00
	CORE		353.92	353.92	353.92	1061.76
	FTEs		2.00	3.00	3.00	8.00

sMDT: M&S and Construction (UMich)

- Basis of Estimate taken from current tooling costs already developed at MPI taking into account existing infrastructure at Michigan

Components	total (kCHF)
Tube Tooling M&S costs (k$)	**400**
semi-automated tube assembly tooling	100
automated gluing machine, jigging, QC equipment	100
Tube test stations, test fixture	50
Chamber test station (gas, HV, and readout)	50
Chamber construction room & humidity system	20
Chamber construction M&S (glue, lab supplies)	18
Chamber shipping construction and shipping	42
Module 0	20

- Existing Infrastructure: Granite table (>$100k), electric tables for tube production (>$40k), He leak detectors (> $20k each), chamber clean room temp and humidity system (> $100k), power pumpers for vacuum used in chamber production, crane and control systems, chamber and test assembly rooms

Components	cost/unit	number units	total (kCHF)
Core cost of BIS 1-6 sMDT's (48 sMDT chambers)			**1061.76**
Al tubes	8	24000	192
Wire (units of km)	1000	40	40
Endplugs	7.2	48000	345.6
Gas connectors	1.8	48000	86.4
Spacers/support	1000	48	48
Faraday cages/chamber	500	48	24
gas distribution/chamber	400	48	19.2
Alignment system / chamber	400	48	19.2
Transport tools	500	48	24
HV and RO distribution boards	95	2240	212.8
Total Construction cost (in kCHF)		48	1011.2
Total cost is USD (1 kCHF = 1.05 kUSD)			**1061.76**
1/3rd the cost - splitting total over 3 years			**353.92**

sMDT: M&S and Construction (UMich)

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)
sMDT	**Total**					**3012.28**
	Labor	275.75	469.51	477.17	292.10	1514.52
	Material	400.00	0.00	0.00	0.00	400.00
	Travel	9.00	9.00	9.00	9.00	36.00
	CORE		353.92	353.92	353.92	1061.76
	FTEs	2.50	5.00	5.50	3.00	16.00
Tooling Construction	Total					0.00
	Labor	275.75	168.09			443.84
	Material	400.00				400.00
	Travel	9.00				9.00
	CORE					0.00
	FTEs	2.50	1.50			4.00
Tube Construction	Total					0.00
	Labor		104.33	185.08		289.41
	Material					0.00
	Travel		9.00			9.00
	CORE					0.00
	FTEs		1.50	2.50		4.00
Chamber Construction	Total					0.00
	Labor		197.08	292.10	292.10	781.27
	Material					0.00
	Travel			9.00	9.00	18.00
	CORE		353.92	353.92	353.92	1061.76
	FTEs		2.00	3.00	3.00	8.00

Total Costs and CORE

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)	JUST TDC Total (k$)	VMM Total (k$)	sMDT+VMM Total (k$)	Just sMDT Total (k$)
Muon	**Total**	**2211.86**	**3034.44**	**4262.21**	**5687.19**	**15195.69**	**9405.33**	**9938.15**	**12950.43**	**10172.35**
	Labor	1551.86	2052.52	2143.54	2118.72	7866.64				
	Material	606.00	574.00	155.60	82.34	1417.94				
	Travel	54.00	54.00	54.00	54.00	216.00				
	CORE	0.00	353.92	1909.07	3432.13	5695.12	**3728.21**	**3983.36**	**5045.12**	**4139.97**
	FTEs	14.17	18.66	20.68	20.68	74.19				
PCB for Mezzanine	**Total**	**132.21**	**221.65**	**348.20**	**1435.54**	**2137.60**	**2137.60**	**2137.60**	**2137.60**	**2137.60**
	Labor	102.21	169.65	210.60	327.19	809.65				
	Material	21.00	43.00	128.60	35.34	227.94				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1064.01	1064.01	**1064.01**	**1064.01**	**1064.01**	**1064.01**
	FTEs	1.17	1.66	3.18	5.68	11.69				
TDC	**Total**	**456.63**	**455.41**	**994.45**	**338.77**	**2245.26**	**2245.26**			
	Labor	292.63	301.41	310.45	319.77	1224.26				
	Material	155.00	145.00	25.00	10.00	335.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE	0.00	0.00	650.00	0.00	650.00	**650.00**			
	FTEs	3.00	3.00	3.00	3.00	12.00				
CSM	**Total**	**394.79**	**385.76**	**397.07**	**1690.99**	**2868.61**	**2868.61**	**2868.61**	**2868.61**	**2868.61**
	Labor	365.79	376.76	388.07	399.71	1530.33				
	Material	20.00	0.00	0.00	35.00	55.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1247.28	1247.28	**1247.28**	**1247.28**	**1247.28**	**1247.28**
	FTEs	4.00	4.00	4.00	4.00	16.00				
sMDT	**Total**	**684.75**	**832.43**	**840.09**	**655.02**	**3012.28**			**3012.28**	**3012.28**
	Labor	275.75	469.51	477.17	292.10	1514.52				
	Material	400.00	0.00	0.00	0.00	400.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE		353.92	353.92	353.92	1061.76			**1061.76**	**1061.76**
	FTEs	2.50	5.00	5.50	3.00	16.00				
HEB	**Total**	**336.17**	**345.69**	**347.49**	**1124.50**	**2153.85**	**2153.85**	**2153.85**	**2153.85**	**2153.85**
	Labor	317.17	326.69	336.49	346.58	1326.93				
	Material	10.00	10.00	2.00	2.00	24.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				766.92	766.92	**766.92**	**766.92**	**766.92**	**766.92**
	FTEs	2.00	2.00	2.00	2.00	8.00				
TDC	**Total**	**207.30**	**793.50**	**1334.91**	**442.38**	**2778.08**		**2778.08**	**2778.08**	
	Labor	198.30	408.50	420.76	433.38	1460.93				
	Material	0.00	376.00	0.00	0.00	376.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE			905.15		905.15		**905.15**	**905.15**	
	FTEs	1.50	3.00	3.00	3.00	10.50				

JOG = $9.9M

MUON ATLAS CORE = $35.8M

Total Costs and CORE

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)	JUST TDC Total (k$)	VMM Total (k$)	sMDT+VMM Total (k$)	Just sMDT Total (k$)
Muon	**Total**	**2211.86**	**3034.44**	**4262.21**	**5687.19**	**15195.69**	**9405.33**	**9938.15**	**12950.43**	**10172.35**
	Labor	1551.86	2052.52	2143.54	2118.72	7866.64				
	Material	606.00	574.00	155.60	82.34	1417.94				
	Travel	54.00	54.00	54.00	54.00	216.00				
	CORE	0.00	353.92	1909.07	3432.13	5695.12	**3728.21**	**3983.36**	**5045.12**	**4139.97**
	FTEs	14.17	18.66	20.68	20.68	74.19				
PCB for Mezzanine	**Total**	**132.21**	**221.65**	**348.20**	**1435.54**	**2137.60**	**2137.60**	**2137.60**	**2137.60**	**2137.60**
	Labor	102.21	169.65	210.60	327.19	809.65				
	Material	21.00	43.00	128.60	35.34	227.94				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1064.01	1064.01	**1064.01**	**1064.01**	**1064.01**	**1064.01**
	FTEs	1.17	1.66	3.18	5.68	11.69				
TDC	**Total**	**456.63**	**455.41**	**994.45**	**338.77**	**2245.26**	**2245.26**			
	Labor	292.63	301.41	310.45	319.77	1224.26				
	Material	155.00	145.00	25.00	10.00	335.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE	0.00	0.00	650.00	0.00	650.00	**650.00**			
	FTEs	3.00	3.00	3.00	3.00	12.00				
CSM	**Total**	**394.79**	**385.76**	**397.07**	**1690.99**	**2868.61**	**2868.61**	**2868.61**	**2868.61**	**2868.61**
	Labor	365.79	376.76	388.07	399.71	1530.33				
	Material	20.00	0.00	0.00	35.00	55.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1247.28	1247.28	**1247.28**	**1247.28**	**1247.28**	**1247.28**
	FTEs	4.00	4.00	4.00	4.00	16.00				
sMDT	**Total**	**684.75**	**832.43**	**840.09**	**655.02**	**3012.28**				
	Labor	275.75	469.51	477.17	292.10	1514.52				
	Material	400.00	0.00	0.00	0.00	400.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE		353.92	353.92	353.92	1061.76				
	FTEs	2.50	5.00	5.50	3.00	16.00				
HEB	**Total**	**336.17**	**345.69**	**347.49**	**1124.50**	**2153.85**				
	Labor	317.17	326.69	336.49	346.58	1326.93				
	Material	10.00	10.00	2.00	2.00	24.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				766.92	766.92				
	FTEs	2.00	2.00	2.00	2.00	8.00				
TDC	**Total**	**207.30**	**793.50**	**1334.91**	**442.38**	**2778.08**				
	Labor	198.30	408.50	420.76	433.38	1460.93				
	Material	0.00	376.00	0.00	0.00	376.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE			905.15		905.15				
	FTEs	1.50	3.00	3.00	3.00	10.50				

WBS	Item	Reference Total Cost [kCHF]
5	**Muon system**	**34,084**
5.1	MDT	7,692
5.1.1	sMDT detector	2,022
5.1.2	sMDT installation basket	20
5.1.3	Mezzanine cards	4,000
5.1.4	CSM cards	1,650

JOG = $9.9M

MUON ATLAS CORE = $35.8M

% CORE ~ 15%

Prioritization

Description	AY k$	FY20	FY21	FY22	FY23	Total (k$)	JUST TDC Total (k$)	VMM Total (k$)	sMDT+VMM Total (k$)	Just sMDT Total (k$)
Muon	Total	2211.86	3034.44	4262.21	5687.19	15195.69	9405.33	9938.15	12950.43	10172.35
	Labor	1551.86	2052.52	2143.54	2118.72	7866.64				
	Material	606.00	574.00	155.60	82.34	1417.94				
	Travel	54.00	54.00	54.00	54.00	216.00				
	CORE	0.00	353.92	1909.07	3432.13	5695.12	3728.21	3983.36	5045.12	4139.97
	FTEs	14.17	18.66	20.68	20.68	74.19				
PCB for Mezzanine	Total	132.21	221.65	348.20	1435.54	2137.60	2137.60	2137.60	2137.60	2137.60
	Labor	102.21	169.65	210.60	327.19	809.65				
	Material	21.00	43.00	128.60	35.34	227.94				
2	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1064.01	1064.01	1064.01	1064.01	1064.01	1064.01
	FTEs	1.17	1.66	3.18	5.68	11.69				
TDC	Total	456.63	455.41	994.45	338.77	2245.26	2245.26			
	Labor	292.63	301.41	310.45	319.77	1224.26				
5	Material	155.00	145.00	25.00	10.00	335.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE	0.00	0.00	650.00	0.00	650.00	650.00			
	FTEs	3.00	3.00	3.00	3.00	12.00				
CSM	Total	394.79	385.76	397.07	1690.99	2868.61	2868.61	2868.61	2868.61	2868.61
	Labor	365.79	376.76	388.07	399.71	1530.33				
1	Material	20.00	0.00	0.00	35.00	55.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				1247.28	1247.28	1247.28	1247.28	1247.28	1247.28
	FTEs	4.00	4.00	4.00	4.00	16.00				
sMDT	Total	684.75	832.43	840.09	655.02	3012.28			3012.28	3012.28
	Labor	275.75	469.51	477.17	292.10	1514.52				
4	Material	400.00	0.00	0.00	0.00	400.00				
	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE		353.92	353.92	353.92	1061.76			1061.76	1061.76
	FTEs	2.50	5.00	5.50	3.00	16.00				
HEB	Total	336.17	345.69	347.49	1124.50	2153.85	2153.85	2153.85	2153.85	2153.85
	Labor	317.17	326.69	336.49	346.58	1326.93				
	Material	10.00	10.00	2.00	2.00	24.00				
3	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE				766.92	766.92	766.92	766.92	766.92	766.92
	FTEs	2.00	2.00	2.00	2.00	8.00				
TDC	Total	207.30	793.50	1334.91	442.38	2778.08		2778.08	2778.08	
	Labor	198.30	408.50	420.76	433.38	1460.93				
	Material	0.00	376.00	0.00	0.00	376.00				
5	Travel	9.00	9.00	9.00	9.00	36.00				
	CORE			905.15		905.15		905.15	905.15	
	FTEs	1.50	3.00	3.00	3.00	10.50				

5 **Entirely based on international overlap with Japan and MPI - both of which already have assured funding for all construction**

Final Comments

- Impact:
  - From ATLAS muon management point of view, the CSM and sMDT projects seem highest priority
- Major Assumptions:
  - sMDT's will be used with RPC's at BI - as opposed to MM or some other solution
  - Japan will be able to afford (in $ and Watts) an FPGA-based TDC or MPI will be allowed to develop an asic-based TDC in 130 nm technology
  - Difficult to gauge just how much Japan and MPI will actually do…
- Some Remarks:
  - We are fairly invariant to ATLAS decisions. Projects are high priority and exist in some form in all ATLAS scoping scenarios.
  - Guidance on system integration manager would be helpful (more detail on role)